RESIDENTIAL COMBUSTION SAFETY CHECKLISTS

A Report Prepared for:
The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

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by:
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SUMMARY

The Combustion Safety Checklists presented in this report follow two CMHC reports completed in 1983-84: a report by Hatch Associates on Hazardous Heating and Ventilating Conditions in Canadian Housing, and a report by Sheltair Scientific on the design and evaluation of a Residential Chimney Backdraft Checklist. This report attempts to respond to the growing hazard of chimney failures in housing, identified in the Hatch report, by expanding the scope and applicability of the original Chimney Backdraft Checklist.

The project objective was to develop procedures for identifying and remedying problems with vented combustion heating appliances in Canadian housing.

The research included three principle tasks:

- the design of two checklists, one for tradesmen and another for householders;
- the field testing of both checklists on 20 houses in each of 5 regions across Canada; and,
- the application and evaluation of suitable remedial measures on houses with problems.

As part of the Checklist design phase, an exploration of failure mechanisms was undertaken. It included discussions with industry personnel, tests on condemned appliances and complaint houses, and the intentional modification of houses and chimneys, in order to simulate problem situations. Various identification technologies were evaluated, and the range of potential failures, suitable for recognition by the Checklists was classified. The failure mechanisms include:

- backdrafting of furnace and water heater chimneys, due to a significant

imbalance in the intake and exhaust flows of household ventilation systems,

- spillage from chimneys, due to blockage or breakage in the flue;
- spillage from chimneys, due to overfiring of the appliance, or poor chimney design;
- spillage or cross-contamination of gases in a furnace, due to a leaky heat exchanger; and,
- spillage from fireplaces during low burn as a result of house depressurization.

The Checklist, for use by trades or contractors, is referred to as the **Combustion Venting Safety Check** (or Safety Check, for short). It is a comprehensive procedure, designed to identify any of the failures listed above. Other design features include:

- all results and procedures are summarized on a single two-sided form;
- a modular step-by-step approach allows flexibility in application, and an effective use of time;
- 'check-off' boxes are provided on the form, to guide the user easily through each part of the test, while ensuring that procedures are safe and thorough;
- it is applicable to all standard houses with conventional heating and ventilating systems, including houses heated with oil, gas, and/or wood, and houses with any variety of exhaust equipment or two-way fan systems;
- an on-site time for testing is approximately 1 1/2 hours, and an initial investment in tools of less than $300;

- no special weather requirements;

- no trade licenses are required by users of the Safety Check; and,

- special test routines for failure houses have been provided to help users diagnose the problem.

The Householders Checklist is referred to as the **Chimney Safety Test**, and is appended to this report in a brochure format, with three sections : an Introduction, a 10 STEP Procedure, and Guidelines for assisting householders with ventilation problems. The Householders' Checklist is less accurate than the Safety Check is restricted to calm, warmer weather, and does not attempt to identify such failures as leaky heat exchangers, CO production, overfiring, and chimney design flaws. It consists primarily of a performance test, in which worst case conditions are intentionally created in the house, and the chimneys are checked for signs of flow reversal when cold, or spillage when hot.

The Safety Check procedure uses an inclined manometer to test for backdraft potential. House depressurization, under worst-case conditions, is compared with a nominal Maximum Allowable Depressurization (MAD) limit, defined for that particular appliance and chimney.

Heat exchanger leakage is revealed by pressurizing the furnace with the circulating blower, and then smoke testing for air flow out of the combustion chamber.

Spillage due to chimney blockage or breakage is determined by smoke testing the chimney system during operation, under worst-case conditions. Continuous spillage for longer than 15 seconds is deemed a failure.

A detailed preventative inspection of chimneys is conducted, to identify design flaws or maintenance requirements.

Gas meters are timed to calculate percentage over- (or under) firing. Flue gas is sampled for CO concentrations.

The Safety Check was field tested on a 100 house sample, selected to represent a variety of systems and especially to include house types thought to be prone to failures. Regions included Ottawa, B.C., Toronto, Manitoba, and P.E.I. Houses were mostly single detached, with gas-fired air furnaces (65%) or oil-fired furnaces (27%). Seventy-seven percent had at least one fireplace.

Forty-five percent of the houses required specific maintenance work, with little consistency in the types of problems identified.

Thirty-six percent of the houses failed the backdraft test by exceeding the MAD limits. The average depressurization by mechanical exhaust, was 3.2 Pascals. On average, the operation of furnace blowers further reduced pressures in the furnace room.

Average depressurization, by fans and fireplaces combined, was 4.5 Pascals.

One home (2% of sample) failed the Heat Exchanger Leakage Test.

Seventeen homes (or 34%) failed the operating Spillage Test.

In thirty-five percent of the houses, depressurization of the fireplace room, with the fire off, exceeded the allowable limit of 3.0 Pascals. The extent of fireplace room failures, and furnace spillage failures, may be underestimated, because multiple failures in houses complicated the test procedure.

Cautionary labels were applied by field evaluators as a way of informing and alerting occupants about unsafe operating conditions. The two most common labels were - "Do Not Block or Restrict This Opening" (19), and "Provide Additional Air Supply from Outside While Operating this Fireplace" (25).

Average time required by field evaluators, on-site, was 1.7 hours per house.

Comments submitted by field evaluators helped produce a final and revised Safety Check, (presented in Appendix 1). Evaluators were able to read depressurization levels accurately, to 0.2 Pascals, (except in very windy conditions), and were generally pleased with the test design, (except in cases where multiple failures occurred in a single house).

Remedial measures were proposed for all houses suffering from major ventilation failures, and eleven of these houses were selected for field evaluations. Emphasis was placed on a group of "priority" measures, thought to be especially appropriate due to low-cost and wide applicability. Priority measures comprised:

- forced and tempered air supply systems, using a duct fan, thermistor and proportional heater interlocked with the house systems;

- direct air supply for clothes dryers, using a kit to balance air exhaust from dryers;

- fail-safe devices for gas water heaters, using a thermo-disc on the draft hood, to shut off the appliance in the event of spillage;

- alarms for gas-fired furnaces, using a double-throw thermo-disc and buzzer, mounted in front of the dilution air inlet opening, to sound an alarm in the event of spillage during furnace operation;

- delayed action solenoid valves for oil furnaces, used to delay ignition so the squirrel-cage burner fan has time to establish proper chimney draft;

- direct air supply to fireplaces, using the ash clean out pit below the fireplace as a convenient and safe make-up air supply route; and,

- balancing forced air distribution systems by adjusting dampers, sealing ductwork with aluminum tape, adding warm air registers or air returns, or by connecting a fresh air duct to the cold air return plenum.

Case studies are presented on houses receiving remedial measures, with details on costs and procedures. In addition to the "priority" measures, the field applications included balancing an air-to-air heat exchanger, sealing a leaky flue connector, installing a passive air supply to furnace room (using an air conditioner diffuser and barometric damper), using a relay switch to interlock a stove-top barbecue fan with an oil burner; extending a flue to improve draft; and replacing a circuitous, poorly designed flue connector.

In all cases, the remedial measures succeeded in improving the ventilation systems so that a repeat of the Safety Check either passed the house, or resulted in a fail-safe situation. Choice of the most appropriate remedial measure for a house is a complex decision, involving many non-technical factors.

The greatest difficulty encountered, with proposing and installing remedial measures, was the lack of suitable alternatives to the open fireplace. The conventional solution of glass doors and direct air supply was not found appropriate, due to high costs and minimal improvement in venting safety.

Another difficulty in selecting appropriate remedial measures was trying to match the cost of remedial measures with the presumed risk, since so little is presently understood about the severity of failure mechanisms identified by the Safety Check or of health effects of long-term frequent spillage.

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Valuable technical assistance for the project came from an Advisory Committee who generously gave of their time and expertise throughout the project. The Advisory Committee included representatives from the Canadian Gas Association, the Building Energy Technology Transfer Program (EMR), the Canadian Combustion Research Laboratory (EMR), Esso Canada, Consumers Gas, the Canadian Standards Association, and the Canadian General Standards Board.

Through participation on day-long workshops, helpful input was also received from representatives of the University of Toronto, the Ontario Fuels Safety Branch, the Ontario Ministry of Energy, and the Ontario Ministry of Municipal Affairs and Housing.

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Field evaluators received on-site assistance from service personnel of the regional gas utilities, (including Ottawa and Winnipeg Gas, Consumers Gas, and B.C. Hydro). Special thanks is due to the inspectors at B.C. Hydro.

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1.0 INTRODUCTION:

1.1 Background

The Residential Combustion Safety Checklist project is a continuation of research on chimney problems begun by Canadian Mortgage & Housing Corporation in 1983. A survey commissioned by CMHC investigated frequency, severity, and causes of hazardous heating and ventilating conditions in Canadian housing (Ref. 1). This survey revealed that a number of factors were contributing to inadequate venting of combustion products. Contributing factors included: combustion equipment problems; damaged chimney and flues; flow reversal due to the operation of exhaust systems and inadequate air supply; and improper equipment installation and operation. The authors concluded that none of these factors presented insurmountable technical problems and that increased levels of awareness appeared to be the best antidote.

Another report, produced by CMHC (Ref. 2), included a proposal for a simple Checklist procedure, to determine potential for downdrafting in combustion flues. A performance test was proposed, in which "worst case" conditions for a house are created intentionally, and the chimney checked for signs of backdrafting. The application of a backdraft Checklist, by householders or tradesmen, was proposed as a means of identifying and remedying hazardous conditions in Canadian housing. A backdraft Checklist was thought to be of particular value, because tighter building envelopes and increased exhaust air capacity are both contributing to an increase in potential backdraft problems in existing housing stock.

A third research report, produced for CMHC (Ref. 3), presents the results of a field research study, the purpose of which was to further develop the Checklist procedure, and evaluate its safety, validity and ease of implementation, on a variety of houses and heating systems. A comprehensive backdraft research test was developed for this purpose. It utilized depressurization equipment to measure the envelope tightness, exhaust capacities, and chimney backdraft pressures in a sample of houses across Canada.

In all, 50 houses, distributed over five regions of the country, were tested for backdraft potential. Test results were used to produce a revised and standardized procedure, referred to as the Residential Chimney Backdraft Checklist. The final research report concluded that the Checklist was a worthwhile and practical means of identifying backdraft hazards. Research results also indicated that backdrafting problems in chimneys were both complex and widespread among Canadian housing. More field validation work was recommended, as well as the development of additional Checklist procedures that could be carried out in concert with the Backdraft Checklist, in order to reveal potential for chimney spillage under operating conditions, chimney blockage, and other potential failures with combustion ventilation systems.

The Combustion Safety Checklists presented in this report are a direct follow- up to the Residential Chimney Backdraft Checklist, utilizing a similar format, and the same research team.

1.2 Objectives

The objective of this research project was to produce procedures for identifying and remedying problems with vented combustion heating appliances in Canadian housing. The intended product was to be two Checklists, one for technicians or tradesmen, and another for householders. The contract terms of reference defined three major tasks in the development of these Residential Combustion Safety Checklists:

1. Preparation of Residential Combustion Safety Check procedures, incorporating five components: backdraft; exhaust blockage; spillage; leakage of the heat exchanger; and fireplace operation interaction;

2. Field testing of the Checklist in a number of houses, and in various climatic regions of Canada, while correcting or modifying the procedure as necessary; and

3. Preparation and evaluation of recommended remedial measures, in situations where a house has failed the Safety Check. From the experience of actual and tested remedial measures, recommendations for remedial measures will be prepared for application to the total Canadian housing stock.

1.3 Research Approach

The research tasks were organized into five phases. These have been briefly summarized below:

Phase 1

- preparation of a comprehensive planning framework
- development of a national research team
- participation in planning workshops in Ottawa, with feedback and input from a representative Advisory Committee.

Phase 2

- a pilot research study on a small sample of houses in B.C., for purposes of better defining the failure mechanisms involved in combustion ventilation hazards in housing.
- testing and evaluation of various techniques and tools for identifying Combustion Ventilation Hazards.
- acquisition of appropriate materials and equipment for use in regional field evaluations.

Phase 3

- preparation of draft 1 of each Checklist.

- experimentation with remedial measures on the samples of houses in B.C.

- selection of 20 test houses in each of five regions of the country, including: B.C., Winnipeg, Toronto, Ottawa, and P.E.I.

Phase 4

- conducting field evaluations of the Checklists, on sample houses in each of the regions.

- obtaining participation and comments from householders, tradesmen, regulatory authorities and utility personnel in each of the regions.

- documentation of failure houses, and comments on Checklist design and suitability. - preparation of proposed remedial measures for failure houses.

Phase 5

- preparation of revised Checklists incorporating comments and suggestions from regions.

- application, evaluation and documentation of remedial measures on a subset of failure houses in the regions.

- submission of final report.

2.0 DESIGN OF THE CHECKLISTS:

Two separate checklists are described in this report. The first is a checklist for use by tradesmen or technicians and is titled the Combustion Ventilation Safety Check, (or Safety Check for short). The Safety Check consists of a two-sided form and a 50 page procedures manual. Due to space limitations, the final version of the Safety Check is separately presented as Appendix I of this report.

The second checklist is designed for use by householders with gas-fired heating systems, and is titled the Chimney Safety Test. The householders' checklist consists of a three part brochure, including an introduction, a 10 step procedure, and a section on problem solving. The Chimney Safety Test is separately bound as Appendix II of this report.

2.1 Problem Definition

Prior to the design of the Checklists, research was undertaken to explore the nature of the problems that might be encountered. Information was

COMBUSTION VENTILATION SAFETY CHECK

Results Summary

Address Street Municipality Arr. time__:__

Date________ Compl.time__:__

1. CHIMNEY INSPECTION

ALL OK__ NOT DONE__ MAINTENANCE RECOMMENDED__

MAINTENANCE REQ'D__

PROBLEMS (specify A1 A2,etc) ______________________________

INSPECTION LIST: (FURNACE=A DHW=B FIREPLACE=C)

1 cap needs repair
2 clearance insufficient
3 supports inadequate
4 brickwork needs repair
5 top sooted or stained
6 lining needs repair
7 lining missing (gas)
8 creosote excessive
9 flue wrong size
10 flue connector loose
11 flue connector corroded
12 damper imbalanced
13 hood stained or rusted
14 connector design problem
15 fuel odors present
16 blower compartment loose
17 filter plugged
18 burner dirty or sooted
19 air supply plugged
20 inlet poorly located

2. FURNACE ROOM VENT/PRESSURE TEST

ALL OK __ NOT DONE __ N/A __ INITIAL FAILURE __

Initial Pressure: FANS 2way___ exhaust___ blower___
FIRE sm___ lg___

Reduced Pressure: FANS 2way___ exhaust___ blower___
FIRE sm___ lg___

Relief Measures Taken: ______________________________

CLOSE: ext doors __ windows __ int doors __

TURN OFF: furnace pilot __ DHW __ stove __

SET UP: tubing __ gauge __

CLOSE INLETS:furnace rm__ house__ firepl__

CLOSE CHIMNEYS: furn__ DHW__ fpl dampers__

FANS OFF & COVERS REMOVED: __

ZERO GAUGE: __

OPERATE FANS: range __ stovetop __ bath1 __ bath2__
bath3__ dryer__ vacuum __ special __

RECORD PRESSURES: fans on __ blower on __
(Fails? inlets open__ labels applied__)

PREPARE SM FPL: window open__ chimney open__ air supply
open__ firepl doors open__ burner high__
check draft __ window closed__

CHECK FPL SPILLAGE: __(Fails? close firepl OR open window__
apply label__)

RECORD PRESSURE: __ (Fails? close fireplace doors __ apply
labels__)

3. HEAT EXCHANGER LEAKAGE TEST

ALL OK __ NOT DONE __ SLIGHT FAILURE __ MAJOR FAILURE __

Describe leakage:____

GAS

PREPARATION: pilot light off __ flue still plugged __

PREPARE EQUIPMENT: smoke ready __ light on __

SMOKE CHECK PORTS WITH BLOWER OFF: bottom __ top __

TEST LEAKAGE: blower on __ repeat smoke checks __

RESET FURNACE: blower off__ chimney open__ pilot lit__

OIL

PREPARATION: ensure burner off __ flue still plugged __
register open __ port open __
smoke candle & lighter ready __

PREPARE EQUIPMENT: smoke ready __ port open __

SMOKE CHECK PORTS WITH BLOWER OFF: bottom __ top __

TEST LEAKAGE: blower on __ repeat smoke check __

RESET FURNACE: blower off __ chimney open __ port closed __

4. FURNACE ROOM SPILLAGE

ALL OK __ SPILL FAILURE __ OVERFIRING__ EXCESS CO __

LOW DRAFT__

Furnace: none__ temporary(sec)____ continuous__; slight__ major__

DHW: none__ temporary(sec)____ continuous__; slight__ major__

Gas Furnace Firing Rate: actual______ nominal______

% overfiring _____ CO ppm___

Gas DHW Firing Rate: actual______ nominal______

% overfiring _____ CO ppm___

Oil Furnace Draft Measurement (Pascals)_____

ENSURE CONTINUED OPERATION: fans __ fireplaces __

FURNACE OPERATION: open flues__ stand aside__ turn it on__

OBSERVE & TIME SPILLAGE: port__ hood__ damper__ joins__

RECHECK SPILLAGE AFTER BLOWER OPERATES:__

MEASURE OIL CHIMNEY DRAFT: connect static tip__ record draft__

CLOCK GAS METER: record seconds__ cubic feet__ BTU/HR__

RECORD FIRING RATES: actual__ nominal__ % calculation__

SAMPLE CO IN FLUE GAS: hand pump__ record ppm__

DHW OPERATION: turn it on__ recheck spillage__ sample CO__

record CO ppm__

5. FIREPLACE VENT/PRESSURE TEST

ALL OK __ NOT DONE __ INITIAL FAILURE __

SML:(Pa)____; repeated with: inlets open____, doors shut____, lg fpl off____, or relief opening req'd of _____mm X_____mm

LGE:(Pa)____; repeated with: inlets open____, doors shut____, lg fpl off____, or relief opening req'd of _____mm X_____mm

ENSURE CONT. OPERATION: fans __ furnace __ DHW __ lg/sm fpl__

RELOCATE INDOOR TUBE TO FIREPLACE ROOM: small __ large __

PREPARE SM/LG FIREPLACE: burner off __ air inlets open __

chimney damper closed __

fireplace doors open __

RECORD PRESSURE: ___ (Fails? determine best remedial measure:

1. open any inlets to furnace rm or house ___ passes ___
2. close any fpl doors & relocate tubing ___ passes ___
3. shut off any other fpl ___ passes ___

COMPLETION

ENSURE FLUES OPEN: furnace ___ DHW ___ stove ___

OPEN INLETS: furnace rm___ house___ crawl spc___

RESET: furnace pilot___ thermostat___ DHW valve___

CHECK FURNACE OPERATION: full cycle___ flame color___ fans___
fireplace dampers___ ___

A RECORD OF REMEDIAL ACTIONS TAKEN

LABELS APPLIED

Exhaust Fan ____ Combustion air ____ Fresh air____ Blower____

Sml Fireplace____ Lge Fireplace____ Furnace ____ DHW ____

ADVICE TO OCCUPANT

Verbal Explanation ___

Literature ____

Referral to ____

INLET INSTALLED

Size ____

Location ____

OTHER WORK ____

FOLLOW-UP REQUIRED

None___ Urgent___ Today___ Routine___ Optional___

(Details:) ____

TABLE 1: SUGGESTED TOOL LIST

1 INSPECTION:

__ adj. mirror
__ flash
__ ratchet
__ multi-screwdriver
__ binoculars
__ tape measure
__ fan labels
__ inlet labels
__ fireplace labels

3 HEAT EXCHANGER:

__ smoke extension kit
__ smoke pencil

4 CHIMNEY SPILLAGE:

__ propane stove
__ butane lighter
__ timepiece
__ hand pump
__ CO tubes
__ static pressure tip

2&5 FURNACE OR FIREPLACE ROOM TESTING:

__ manometer
__ tubing & connectors
__ 3" masking tape
__ balloons & tube

FIREPLACES:

__ propane stovetop
__ butane lighter
__ propane canister

TABLE 2: MAXIMUM ALLOWABLE DEPRESSURIZATION (MAD Limits)

APPLIANCE	IGNITION	DRAFT	TOTAL CHIMNEY HEIGHT (m)	LIMIT (Pa)
Gas-fired DHW	pilot	natural	NA	3.0
	electronic	natural	NA	2.0
	electronic	induced	NA	5.0
Oil-fired DHW	electronic	natural	NA	4.0
Gas furnace/ boiler	pilot	natural	2 - 4	4.0
	pilot	natural	4 - 8	5.0
	electronic	natural	2 - 4	3.0
	electronic	natural	4 - 8	4.0
	electronic	induced	NA	6.0
	pilot	forced	NA	6.0
Oil furnace/ boiler	electronic	natural	NA	4.0
	pilot	forced	NA	4.0
Fireplaces	NA	natural	NA	3.0

FIRING RATE CALCULATIONS

$$\text{Thousand BTU/hr Input} = \frac{\text{seconds req'd for dial to record 1 ft3}}{3852}$$

$$\text{Percentage Overfiring} = \frac{\text{actual rate - nominal rate} \quad * \ 100}{\text{nominal rate}}$$

collected on the specific failure mechanisms that can occur with heating systems, on the major contributing factors involved in failure incidence, the types of symptoms that could be looked for when failures occur, and the frequency and severity of various failures. Much of the information collected on ventilation failures has been summarized and separately presented as Appendix III of this report.

The exploratory research was conducted in three phases:

- a literature review, with special attention given to the many carbon monoxide poisoning events summarized in the Hatch Report (Ref. 2);
- discussions with industry personnel including manufacturers, regulatory personnel, field inspectors, and servicemen; and,
- a series of field research projects in which ventilation failures were provoked in houses and the results observed, or in which inspectors were accompanied to houses already experiencing problems and the mechanisms documented, in detail, on-site.

A comprehensive list of failure mechanisms was identified and categorized as follows:

- backdrafting of furnace and water heater chimneys, due to imbalance in household ventilation systems;
- spillage from chimneys, due to blockage or breakage in the flue;
- spillage from chimneys, due to overfiring of the appliance or poor chimney design;
- spillage or cross-contamination of gases in a furnace, due to a leaky heat exchanger; and,

- spillage from fireplaces during low burn, as a result of house depressurization.

In many cases, the occurrence of such failure mechanisms in combustion ventilation systems does not involve generation of carbon monoxide. It is assumed, however, that all such events are potentially hazardous to householders. This assumption has been made for three reasons:

i. Many householders would find the unintended spillage of combustion gases to be unacceptable, even in the absence of CO, because of the high amounts of humidity that are experienced, the stale and stuffy air, and the many trace elements that can accompany spillage of combustion gases in a house.

   A number of householders participating in this study were experiencing problems from spillage (such as odors and headaches) despite the absence of CO. These problems appeared to be significant (although no attempt has been made to document such incidents). The extent of risk is a complex issue that includes such factors as the householders' sensitivity, the air change rates, and the exposure concentrations.

ii. Because CO is such an extremely dangerous gas, and its generation somewhat unpredictable at present, it is assumed that any amount of spillage is unacceptable. As long as none of the chimney failure mechanisms are occurring, a safety margin exists that will protect occupants regardless of the CO levels in the combustion gases.

iii. The severity of any particular failure mechanism is difficult to assess because, over time, the venting system can degenerate. For example:

   - overfiring of a gas appliance, can lead to: poor combustion; carbon monoxide production; a sooty flame, and eventual blockage of the flue and spillage of combustion gases. Or,

- backdrafting of an oil furnace, at start-up, can lead to: a sooty combustion chamber; a sooty flue connector; a sooty furnace burner; poor air delivery and further sooting; poor drafting in the constricted flue connector and further sooting; and eventually, continuous spillage due to blockage of a flue. Or,

- a small leak in the heat exchanger can lead to: a differential cooling of the heat exchanger and further leakage; poor air mixing in the combustion chamber, with carbon monoxide production or sooty flame, pressurization of the combustion chamber, with subsequent spillage through the dilution air inlet; or poor combustion, leading to sooting and blockage of the heat exchanger, or flue connector, with subsequent spillage.

The complexity of failures in combustion venting systems is well-illustrated in the reported incidents of carbon monoxide poisonings in Canada, outlined in the Hatch Report (Ref. 2). Many of these incidences are examples of multiple failures, and progressive degeneration of the venting system.

2.2 Design Principles for the Safety Check

The initial Safety Check design was influenced by a number of design objectives, arising out of discussions with the CMHC Project Manager, the project Advisory Committee, and various industry personnel. Some ambiguity in the design objectives was unavoidable, since it was unclear who the specific users of the Safety Check might be. Ideally, a Checklist would be tailored to meet the specific needs and abilities of the users, and to fit the physical characteristics of the housing stock to be tested. The challenge for this research project was to produce a Checklist that was generic enough to be used in almost any situation.

Some of the guiding principles used in preparation of the Safety Check have been briefly outlined below:

- **Emphasize a Checklist for the industry before a Checklist for householders**

A consensus was developed, during the workshops with the Advisory Committee, to place a greater emphasis on developing a workable Checklist for use by tradesmen (rather than householders). A standardized procedure, for use by the trades, was felt to be a higher priority because nothing currently existed, and because tradesmen would need recourse when and if householders begin performing tests on their houses.

- **Comprehensive in recognition of hazards.**

It was felt that a Safety Check should be capable of identifying all types of combustion ventilation failures in houses, so that after completion of a Safety Check, a householder can be reasonably sure that the house is safe from spillage of combustion gases, (at least in the near future). A comprehensive approach is justified, on the grounds that failure mechanisms are complex, interactive, and not well understood at present. The degree of risk is also an unknown factor and, thus, no type of failure can be safely ignored.

- **Modularized and Integrated**

The Safety Check should be designed in a step-by-step fashion so that only those procedures that apply to the particular house need be employed. However, each of the steps is designed in such a way as to be easily integrated, with steps coming before and after, for an efficient use of time.

- **Applicable to a wide range of housing**

The Safety Check should be capable of checking all standard types of houses and heating systems. In particular, it should apply to all conventional, naturally aspirated, gas, oil, propane, or wood-fired heating systems. The Safety Check should also accommodate all typical kinds of exhaust systems and controls in houses, including such special features as air-to-air heat exchanger systems, continuous two-speed circulating blowers, houses with two fireplaces, and houses with fireplaces that have doors, inlets and other accessories. Not included in the housing target group, as presently defined, would be row houses, multiple unit dwellings and apartments.

- **Low Cost and Practical**

In order for the Safety Check to be usable by tradesmen on a day-to-day basis, and as part of existing market practices, it is felt that the time requirement must be no more than an hour and a half, the initial investment in equipment should be no more than several hundred dollars, and the procedure be suitable for use under most kinds of weather conditions.

- **Suitable for use by any tradesmen**

Because the Safety Check is needed for so many houses across the country, and because the Safety Check requires working on a wide variety of systems, it was felt that the object should be to develop a procedure that did not require the user to have any special licenses for working on particular equipment in houses. In this way, the Safety Check could be adopted by whatever trades felt that it might be of value in their regular work.

This objective required, in turn, that the procedure not involve the adjustment or operation of any controls or systems that would not normally be adjusted or operated by householders. The procedure also needed to be extremely simple to read and follow, with a variety of fail-safes and quality control mechanisms, to ensure that execution of the Safety Check does not create potentially unsafe conditions in a house.

- **Capable of Diagnosing the problem**

Due to the complexity of ventilation problems in houses, and the frequency with which these problems are likely to be encountered, it is felt that any Safety Check should incorporate procedures to assist the user in diagnosing a particular problem. A more detailed procedure is justifiable, therefore, if it can help the user pinpoint why a particular house has failed part of the Safety Check, and assist the user in prescribing the most appropriate remedial measure.

2.3 Design Features of the Householders Checklist

The object of the Chimney Safety Test is - to provide householders with a means of easily recognizing potential for hazardous spillage, or backdrafting, from gas-fired appliances or wood fireplaces; and - to provide directions on how to resolve problems encountered while conducting the Checklist. The audience, scope, and format of the Chimney Safety Test are described below:

Audience: This Checklist has been targeted at those householders who are both literate, and concerned about chimney safety. While technical language has been kept to a minimum, it is assumed that the audience is capable of comprehending the basics of chimney operation. The explanations in the introductory and concluding sections are intended to improve understanding and awareness. It is hoped that complex concepts, and new language, can be gently introduced through creative formatting and the use of graphics.

Field evaluations were conducted, in which householders conducted a Checklist similar to the Chimney Safety Test (ref.3). Few major difficulties were encountered, (although the participants were well educated and, for one reason or another, already concerned with the issue of indoor combustion pollution). To further dilute the technical content of the Checklist, in order to broaden the audience, would increase the risk of incorrect or unsafe applications.

Scope: The Checklist has been designed for use only with conventional, naturally aspired gas-fired furnaces, water heaters and open wood fireplaces. This includes the vast majority of houses exposed to potentially hazardous backdrafting and spillage while, at the same time, eliminating an unnecessarily wordy and complex checklist. A separate Checklist, designed on similar parameters, could be developed (at a later stage) for houses with oil-fired heating systems.

The Checklist begins with an inspection procedure, which should be capable of identifying some of the worst maintenance hazards. The remainder of the Checklist is designed to identify the following conditions:

- backdrafting potential for furnaces and water heaters;
- backdrafting and spillage from fireplaces, at full burn;
- backdrafting or spillage from fireplaces, at low burn;
- spillage in water heater or furnace flues, due to blockage, breakage or poor design;
- spillage in fireplaces, due to blockage, excess creosote or poor design.

The Checklist may also reveal spillage due to gross leakage in a furnace heat exchanger, or overfiring of a gas appliance.

Format: The format is intended to facilitate reading and comprehension. The Checklist begins with an Introduction and List of Contents. The test itself is composed of ten steps, each of which would appear on a single page.

When encountering chimney problems or procedural difficulties, the householder is advised to refer to a final section titled: "Where to go from Here". This final Section outlines sources of information, and describes the most appropriate remedial measures to consider, for houses that fail any particular Step in the Checklist. The Checklist thus becomes a means of both understanding and identifying combustion hazards in a house, as well as a means of obtaining appropriate assistance where required.

The value of the Checklist will depend largely on the ability of the householder to follow procedures, and recognize failure mechanisms.

Consequently, a step-by-step, check-off-by-check-off format is essential. The graphic illustrations will also be crucial in communicating the essence of a particular procedure.

2.4 Choice of Identification Technologies

A variety of identification technologies were evaluated during the research design phase. The pros and cons of different approaches have been documented in Appendix III. The final approach chosen for identifying each of the failure mechanisms is briefly summarized below. Each identification procedure is described in complete detail, as part of the Checklists presented in Appendix I and II.

Potential Backdrafting:

The Chimney Safety Test, for householders, uses the actual chimney performance, under worst case conditions, as an indication of backdraft potential of the house. The flame from a butane lighter (or candle) is held close to the dilution air inlet opening, with all exhaust systems operating and the flue cooled to ambient temperature. A safety margin is built into this procedure, by means of temporarily sealing of any special air supply inlets, and the removal of grilles or covers over the exhaust fans. The test is carried out only under calm weather conditions, to avoid wind distortion on chimney draft or building envelope pressures. Outdoor temperatures must be above freezing for testing, to ensure that the chimney draft is reasonably weak during the test.

The only factor which is not ideal during the Checklist is the indoor/outdoor temperature difference. The "worst case" situation occurs when the indoor/outdoor temperature difference is at a minimum. This minimum temperature is difficult to predict for any particular house, and even more difficult to simulate during the test. A reasonable compromise is to require testing during the heating season, but with outdoor temperatures above freezing. As a result, the chimney updraft pressures may exceed the minimums, by an additional 2 or 3 Pascals. In most cases, this variance will fall within the safety margins of the test, although more analysis is required.

The tradesmen's Safety Check makes use of an inclined manometer to test for backdraft potential, thereby improving accuracy and eliminating weather variables. With the chimney plugged, the manometer is used to measure the maximum depressurization, of the furnace room or fireplace room, that will occur under worst case operating conditions. A potential backdraft situation exists only if the level of depressurization exceeds the nominal Maximum Allowable Depressurization (MAD) limit, established for that particular appliance and chimney. The difference between the MAD limits and the depressurization level allows the user to assess the degree of safety margin for the house, or, in the event of failure, to prescribe an appropriate remedial measure.

Heat Exchanger Leakage:

The householders' Checklist does not include any procedures for identifying heat exchanger leakage. It is felt that most householders would lack the basic understanding of heating system operation required to perform a check for leakage. Extreme heat exchanger leakage will result in spillage from the appliance and, therefore, becomes evident during testing for chimney exhaust operation. Minor leakage from heat exchangers is not generally felt to be a serious health and safety hazard.

The tradesmen's Safety Check includes a procedure for checking heat exchangers for both minor and major leakage. The technique is similar for both oil and gas furnaces. It involves cooling of the appliance to room temperatures, plugging of the chimney, and pressurizing of the heat exchanger, by means of operating the furnace circulating blower manually. An extended smoke pencil and penlight are then used to detect any flow of air into the combustion chamber, from the circulating air stream. Leakage areas as small as one square centimetre have been positively and quickly identified using this approach.

Spillage Due to Blockage or Breakage of Chimney:

Both Checklists check for potential chimney blockage or breakage, by means of performance testing and preventative inspections. The performance test involves operation of the appliance, during worst case operating conditions, and a timed check for spillage, at the dilution air inlet opening and other joins and cracks in the chimney system. Any amount of spillage, for a period greater than 15 seconds, is deemed to be a failure. The preventative inspection involves a step-by-step inspection of the chimney, from the exterior and interior, with attention to potential failure mechanisms such as corroded connectors, inadequate supports, deteriorating chimney caps, and broken tile linings.

Spillage Due to Overfiring or Poor Chimney Design:

The Householders' Checklist includes procedures for checking spillage, by means of the performance test described above. No other inspection or test procedures are felt to be appropriate for the householder.

The tradesmen's Safety Check includes additional procedures for checking spillage, due to overfiring and poor chimney design. A timing of gas meters allows the user to compare the actual firing rate with the specified firing rate and determine the percentage under- or over-firing. Colormetric gas sampling tubes are used to sample flue gases during operation and determine carbon monoxide production from gas appliances. Flame characteristics are noted, for problems with luminescent flames on gas appliances, or poor flame spread on oil appliances. And, finally, the geometry of the chimney design and installation is compared with the recommended design features in the CGA Natural Gas Appliance Installation Manual. These additional procedures should be capable of identifying heating systems with potential spillage problems, even in cases where spillage may not be occurring during the time of inspection.

3.0 FIELD EVALUATIONS:

Field evaluations of the Combustion Safety Check were completed on 20 homes in each of the five regions. Safety Checks were conducted by engineers or building technologists, hereafter referred to as field evaluators.

The field evaluations proved useful in a number of ways:

- Major revisions were completed on the Safety Check Form and Procedures, in response to comments and suggestions from field evaluators;

- Issues raised by the Safety Check, that could not be resolved immediately, have indicated fruitful directions for further research on hazardous ventilation and heating systems;

- Data collected, from the Results Summary sections of the Safety Checks provided an indication of the types and numbers of failures that might exist in the typical housing stock.

- The successful completion of the Safety Check on such a large and diverse housing sample, has demonstrated its wide applicability;

- In the process of evaluating the Safety Check, a number of personnel working for fuel suppliers or regulatory bodies, have been introduced to the issues and familiarized with new diagnostic procedures; and

- The field evaluations identified a number of "failure" houses in each region of the country, and have thus provided an appropriate housing sample for application and evaluation of remedial measures.

3.1 SELECTION OF TEST HOUSES

The selection of houses focused on 'problem-prone' houses rather than typical house types. This approach was thought to provide a better trial for the Safety Check, and also allowed for more follow-up work through the implementation of remedial measures. A 'problem-prone' house was defined as a house that might be likely to experience backdrafting, or any other kind of venting problem.

A number of selection strategies were followed by the regional firms:

Including failures from the Chimney Backdraft Project:

In cases where a house had already been tested as part of the Chimney Backdraft Checklist Evaluation (1983-84), and where the house was shown to have venting problems, the house was included in the 20-house sample. This approach allowed the evaluators to concentrate on known failures, and to remedy any problems identified during earlier research work.

Accompanying Service Personnel or Inspectors on complaint calls.

An effort was made to accompany a furnace servicer or utility inspector during a series of complaint calls. Fall is a busy time for these types of calls, since it is often the time when problems occur, or are first noticed. By accompanying the inspector on these calls, it was sometimes possible to make arrangements with the householder to return to the house and complete a "comprehensive" Safety Check, at a more convenient time.

A request was made to each local gas utility, asking the customer service department to permit a "Safety Check Technician" to accompany an experienced field inspector/servicer, for up to two days of complaint calls.

Letters of support were also obtained from the project Advisory Committee, to facilitate introductions and approvals at the local level. A representative from ESSO Canada provided introductions to the local home fuel oil distributors. (Accompanying gas inspectors or oil furnace servicers was a good way to find 'problem' appliances and this approach was used to locate about 30% of the total sample.)

Including houses with problems typical of each region.

The Hatch Report reviewed incidents of CO poisoning and correlated types of venting malfunctions with provinces. The results showed variations in problems according to region. A copy of the appropriate section of the Hatch Report was provided to each region, and was used to guide house selection.

Including air-tight houses.

Any type of vent malfunction is likely to be more dangerous in a tight house, because of the reduced potential for mixing and air exchange. Tighter houses are also more prone to experiencing low indoor pressures, because even small exhaust fans can create an imbalance. For the purposes of this project, the tighter the house the better. The sample in each region was to include several tight houses -- (the new 'R2000' type of house as well as numerous older houses airtightened by professionals).

Advertising directly to householders.

An advertisement was provided to regional firms, for placement in a community newspaper, or as a public service announcement on a local radio station.

3.2 DESCRIPTION OF THE HOUSING SAMPLE:

Combustion Safety Checks were conducted on 100 houses in total. Descriptive information on test houses is summarized in Tables 1 to 5. Each Table includes the 20 houses from a specific region, in the following order:

Table 1	Houses #1 to 20	Ottawa
Table 2	Houses #21 to 40	B. C.
Table 3	Houses #41 to 60	Toronto
Table 4	Houses #61 to 80	Manitoba
Table 5	Houses #81 to 100	P.E.I.

Except for three row houses and four duplexes, the sample includes only single detached houses. The sample provides a fairly representative cross-section of housing styles and ages. Except in the Toronto region, approximately half of the houses had experienced previous ventilation problems. In Toronto, 2 of the 20 houses had experienced previous ventilation problems.

Over 65% of the sample contained gas-fired, forced air furnaces. The remainder were oil-fired furnaces (27%), gas hydronic (6%), wood or propane (4%).

Approximately 77% of the housing sample had at least one wood fireplace, and 20% of these houses had two fireplaces.

3.3 TEST RESULTS FROM SAFETY CHECK EVALUATIONS:

The results of Safety Checks on each test house have been summarized in Tables 6 to 10. Each Table presents the results from a single region, in an identical order to the House Description Summaries (Tables 1 to 5).

Chimney Inspections:

Chimney inspection problems are recorded using the alphanumeric codes listed on the Safety Check form. Approximately 45% of the houses warranted a note on maintenance problems. A majority of problems pertained to furnaces (88%), with the remainder mostly fireplaces. Gas furnaces suffered from a wide variety of problems, with no commonality. Oil furnaces, unlike gas furnaces, were particularly susceptible to corroded flue connectors, damaged caps, and imbalanced barometer dampers.

Furnace Room Depressurization:

Three different pressures (in Pascals) are recorded on Tables 6 to 10, under the column heading "Furnace Room Depressurization". The first pressure is the **Failure Pressure,** recorded only in cases where the depressurization exceeded the Maximum Allowable Depressurization (MAD) limits established for this experiment. The original MAD limits are illustrated in Figure 2.

The Failure Pressure is the depressurization recorded with **all** mechanical exhaust systems and fireplaces operating simultaneously. A Failure Pressure is measured **after** opening or unsealing any air inlets in the houses, and instituting any safety measures already present. A total of 36 houses, out of the 100 house sample, recorded Failure Pressures, and thus may be susceptible to backdrafting hazards.

The **Mechanical Exhaust Pressure** is the maximum depressurization achieved through operation of the combined exhaust systems in a house, with any fresh air inlet ducts closed and sealed. The average Mechanical Exhaust Pressure is 3.2 Pa. The distribution of house Mechanical Exhaust Pressure is graphically illustrated in FIGURE 4. Mechanical exhaust systems include the furnace circulating blower, if the effect of the blower was to depressurize the house. Otherwise the blower was left off.

The **furnace blower operation** usually served to further reduce air pressures in the furnace room, although the effect was unpredictable. In 30 of the houses, the blower depressurized the room, but in another 12 houses, the blower served to pressurize the room. The average effect of the furnace blowers was to depressurize the furnace room by 0.22 Pascals. In the most extreme cases, there was a room depressurization of 5.4 Pascals, and a pressurization of 4.5 Pascals.

The **Mechanical Exhaust plus Fireplace** pressure is the maximum depressurization achieved by operating both fans and fireplaces (with any air inlets still closed). Of course, this pressure is recorded only in cases where a fireplace exists. Wood burning fireplace exhaust was simulated by firing a portable propane stove in the fireplace opening. The average depressurization by fans and fireplaces is 4.5 Pa. The distribution of house pressure is graphically illustrated in FIGURE 5. A comparison of FIGURE 4 and 5 provides an indication of how strongly fireplaces influence depressurization of furnace rooms.

Heat Exchanger Leakage:

The results of the heat exchanger testing is summarized in a single column, as part of Tables 6 to 10. If no positive results were obtained, the leakage is described as NONE. In some cases, the test could not be conducted (boilers, converted units) and the test is classified NOT DONE. Surprisingly, only one furnace in the entire sample indicated signs of leakage. The leakage in this case appeared SLIGHT.

Because the Safety Check procedure was evolving throughout the course of the field evaluations, the techniques used to assess leakage varied from house to house. Initially, the gas furnaces were tested with the sodium salt spray and propane flame, and the oil furnaces with 30 second smoke candles. Later testing used smoke pencil extension kits for all furnaces.

Furnace Spillage Check: The furnace spillage tests involved the timing of spillage, during start-up of the furnace and hot water heater, under worst case conditions. If spillage persisted for a period greater than 15 seconds, the system was deemed a failure. Duration of spillage has also been noted (but only in cases where this was recorded by the field evaluator).

The number of spillage failures totalled 17 houses. More houses would probably have failed this test, had the initial procedures not required proof of updraft prior to firing of the appliance. It was first thought that it would be both dangerous and unrealistic to complete a spillage check on a chimney that was already experiencing a backdrafting failure. Consequently, the "worst case" conditions in the house were often modified to relieve back pressures. However, a consensus was later developed, amongst field evaluators, to perform the test under worst case conditions. This proved to be an easier and more valid test of spillage potential (and of re-establishing updraft if necessary) and did not appear to expose the testor to any significant or unusual hazards.

Fireplace Room Depressurization:

The maximum depressurization experienced by the fireplace room is recorded on Table 6 to 10. These pressures were induced by operation of other exhaust systems - including furnace and DHW and other fireplaces - but with the fireplace itself not burning and its chimney damper shut. A total of 76 houses had fireplaces. Average fireplace room depressurization, for these houses, was 2.4 Pascals. In 34% of these houses the fireplace room depressurization exceeded the allowable limit of 3 Pascals.

These figures, however, can be misleading, because the test procedure was not consistent. Problems arose when trying to continue testing on a house that had failed some part of the Safety Check. Many houses experienced failures during the furnace room depressurization, which required relief measures such as opening inlets, or shutting off fans. Consequently, the maximum fireplace room depressurization figures are much lower than would be the case had the test been completed independently.

Application of Cautionary Labels:

Cautionary labels were applied, by field evaluators, as a way of informing and alerting house occupants about unsafe operating conditions. A reproduction of the cautionary labels, used by field evaluators, is provided in FIGURE 3. The "Labels Required" column, of Tables 6 to 10, record which labels were applied to specific houses.

A review of the labels used for each house provides an indication of what failures occurred, and whether the fresh air inlets were essential for safe operation of chimneys. The two most commonly applied labels were the 19 Combustion Inlet labels (Do Not Block or Restrict This Opening), and the 25 Fireplace labels (Provide Additional Air Supply from Outside While Operating This Fireplace). Labelling fireplaces was often a problem for the field evaluators, because the label needed to be visible without becoming an eyesore.

Time To Complete Test:

Arrival and completion times were recorded by the field evaluators and were used to calculate the approximate duration of the Combustion Safety Check. Times varied from 1 to 3 hours* and are recorded on Tables 6 to 10. Average time on-site, for the entire sample, was 1.7 hours per house.

Time requirements reportedly dropped very quickly as the evaluator gained experience. Multiple failures in houses resulted in considerable delays that would not likely apply in a non-research context. Other major delays encountered by evaluators included:

- talkative householders

- gusty winds

- difficult chimney inspections

- observers (government, utilities, etc.)

* One exceptional house required 4 hours due to delays from multiple and serious failures, imbalanced air-to-air heat exchanger, and a very concerned householder.

3.4 A SUMMARY OF COMMENTS FROM FIELD EVALUATORS:

Field evaluators were requested to record comments on how the Safety Check might be improved, or to describe problems encountered with the current procedure. A number of these comments influenced the final modifications to the Safety Check design. A summary of the comments is produced below:

Chimney Inspections:

1. A need exists to clarify the severity of finding bricks and pieces of masonry or tile in the ash clean out of a chimney, and especially in chimneys where a metal liner already exists.

2. In some cases, it would appear necessary to include, as an optional procedure, the inspection of a problem chimney from the roof.

3. An alternative procedure is needed for inspecting the flue connector when it has been cemented to the vertical chimney.

4. Reference material is required to evaluate whether clearance of a flue

connector, from combustible materials, is adequate for fire safety purposes.

5. The chimney inspection procedures should include a warning for chimneys and appliances that simply need cleaning or annual maintenance, especially where regular maintenance appears to have been neglected.

6. The inspection of the flue and chimney should include a section on poor design of flues, especially flues with many convolutions and/or connections.

7. What should be done when the ash clean out is completely full of ashes and cannot be inspected for masonry items, and/or cannot be used as a port for visually inspecting the rest of the flue? Should householders be asked to clean out these ash clean outs or should the inspector be expected to do so?

Vent/Pressure Testing:

1. The procedure becomes quite difficult to follow and difficult to record in cases where multiple failures occur. A better approach would be to stop and repair any failures before continuing with the check list.

2. It is difficult to define worst case conditions for interior partitions door and air inlets, when testing a house with an enclosed furnace room.

3. When winds are gusty and strong, the manometer can experience pressure situations of plus or minus 2 Pascal, compromising the validity of the test. (Wind problems were noted on four different commentary forms.)

4. Problems encountered when plugging flues can sometimes be frustrating and time consuming. Most often the problem occurs with balloons bursting, and some new piece of technology is needed to simplify this process. (Balloon bursting problems noted three times.)

5. Blowing out pilot light can be potentially dangerous unless technician understands the gas valve technology. It is important to listen for the gas valve to shut off, waiting three minutes or more if necessary. Before proceeding with the test, the technician should ensure that, in fact, the gas has shut off.

6. It is unclear what to do with the operation of two speed circulating blower when initially testing for fan exhaust. Should the low speed, continuous operating mode, exist during the fan depressurization test?

7. Major wind problems were experienced in row housing, due to the significant impact of the building profile on ambient atmospheric pressure. Possibly, row houses should be excluded from check, for this reason, and for problems encountered with interference from systems in neighbouring units.

8. When applying labels during vent pressure testing it may be necessary to discuss application of labels with householders since the labels may raise questions about house operation and of aesthetics.

9. Beware of hidden fresh air intakes, especially four inch diameter ducts connected to return air plenums. Also, beware of hidden dampers on these fresh air intakes.

10. During house preparation, there needs to be guidance for dealing with gas furnaces that have been fitted with barometric dampers.

11. British Columbia houses often have two or more stoves and fireplaces, which makes testing quite difficult.

12. Longer pressure taps may be required, in some cases.

13. The propane stove does not appear to exhaust air from the house at the same rate as a roaring fire using crumpled newspaper. The problem is most significant at higher house pressures. The stove does not appear to be as stiff an exhaust system.

14. In preparation of houses for worst case conditions, allowances must be made for houses with semi-heated crawl spaces. Vents in these crawl spaces allow considerable amounts of air into the house, and should probably be sealed tightly like exterior doors and windows. Further complications result, however, if the house fails the vent pressure test, since these vents may represent essential make up air supply, and may be need to be opened and labelled as such.

15. Some houses pass the test only marginally, (eg.4.5 Pascals versus 5.0 Pascals). Should householders be warned in marginal cases? Perhaps a special label is needed for houses or heating appliances to warn against further reduction in air supply, or an increase in exhaust capacity.

16. During house depressurization the air intakes on airtight wood stoves may spill easily and, if left open, can pollute the house. Closing these air intakes is, perhaps, a required part of the procedure.

17. Evidence of back drafting on furnaces and water heaters should be specifically examined and noted during the inspection.

18. Houses with air-to-air heat exchangers should possibly be dealt with separately. A separate form may be needed, or a separate place to test the air changer before exhaust fans depressurize the house, so as to permit an evaluation of how well the continuous and balanced exhaust systems have been balanced in the house. Hence 'two-way' fans would precede 'exhaust fans' in part two of the procedure.

19. A time delay needs to be specified for the "blower" portion of the vent pressure test. It can take up to a minute or two for the circulating blower or furnace to have its full impact on house depressurization. Also, during this first minute or two, the house pressure may go up or down on a temporary basis.

20. A cautionary label is required for furnace blowers and for air-to-air heat exchangers that significantly depressurize the house.

21. Testing is considerably more difficult when it is dark outside.

22. Trying to plug chimneys, by wrapping the furnace or water heater in a large sheet of plastic (and therefore plugging the air inlets instead of the flue), is an unworkable procedure. Leaks always exist, even after careful taping of plastic.

23. Difficulty was encountered in finding a location to run the exterior pressure tap outside of the house. (Noted on two commentary forms.)

24. In one house, a combustion air supply had already been provided by the householder, because the home smoke alarm had continually gone off. Perhaps a history of smoke alarms going off is an indication of backdraft problems in houses with an oil furnace or DHW heater.

25. Operation of the air-to-air heat exchanger during the vent pressure testing, can be very confusing, and may be misleading. In two cases, technicians felt that the air changer was helping to balance pressure that would otherwise have created failure conditions. In other cases, the technicians felt that air changers should be turned off and the inlets treated as make up air supply inlets under failure conditions. More guidance is required.

26. The occupant of the house was already aware that it was a mistake to operate a clothes dryer and a furnace at the same time and had been acting under that assumption for some time already. This raises the

possibility of interlocking the appliances, or labelling them in a similar fashion to fireplaces.

27. Considerable difficulty was encountered in trying to seal the DHW flue. Perhaps taping around the hood and inlets would be an alternative.

Chimney Spillage and Heat Exchanger Testing:

1. The smoke pencil extension kit works extremely well, although several technicians felt surprised at not discovering any leakage, and thought that perhaps there was something wrong with their technique. A more graphic illustration of how to do this test may be required.

2. The chimney spillage check can be affected by high winds and may be invalid under these conditions.

3. A technique is required for testing heat exchanger and spillage problems on converted oil furnaces using gas power burners.

4. The spillage check should be conducted on the chimney with all other exhaust systems operating (i.e. under worst case back draft conditions), even if an existing back draft is occurring at the time. A failure exists if spillage, or backdraft, does not disappear within the fifteen second limit.

5. More explanation is required, for technician on the proper operation of a barometric damper under varying conditions. Difficulty was reported in trying to understand the effect of spillage, in and out of this damper, and whether the damper is expected to be closed or open under worst case conditions.

6. Technicians should be advised to use the circulating blower to help cool down the furnace in preparation for heat exchanger testing.

7. It may, perhaps, be useful to note the location of any spillage directly on the results summary of the check list.

8. The sodium test is time consuming and does not appear to work well.

9. When finding evidence of leakage using smoke pencil extension kit some guidance is required in assessing the severity of the leak. This is a subjective assessment and small leaks may not necessarily indicate the condemnation of an appliance. (The gas inspectors accompanying the field technicians were adamant on this point.)

10. A special danger exists on furnaces that combine a thermal activated vent damper with electronic ignition, and/or with an energy cycling device. The effect of these energy conserving technologies, on a furnace, is to greatly exacerbate any spillage or backdrafting conditions in the house.

11. Use of smoke candles in oil furnaces is a very confusing procedure. Leakage can occur all along the flue and it is difficult to distinguish this smoke from smoke generated due to a cracked heat exchanger.

12. Difficulty was encountered in getting lit smoke candles into combustion chambers, and in preventing spillage from the combustion chamber during this process.

Fireplace Vent/Pressure Testing:

1. When testing for fireplace backdrafting it is necessary to wait, after turning on the furnace, for the blower to start operating since this will effect the reading on the manometer. A time delay should be specified on the procedural form.

2. When a fireplace fails during the fireplace vent pressure test it is

unclear whether the house and furnace room air supply inlets should be opened as a relief measure.

3. Rezeroing of the manometer is sometimes required over the period between furnace room and fireplace room vent pressure testing.

4. The vent pressure testing did not reveal failure conditions in some houses where householders had complained about serious down draft problems due to winds. (However, inspection of these chimneys sometimes indicated poor geometry around the chimney top.)

5. In several cases during the P.E.I. testing, the technician was unclear as to how to deal with wood stoves that shared the same flue as an oil furnace.

4.0 REMEDIAL MEASURES

4.1 Identification of Appropriate Measures:

To simplify the research task, it was decided to focus the examination of remedial measures upon those techniques that promised to be simple, cost-effective and widely applicable to houses experiencing typical ventilation failures. This "priority" approach to remedial measures is outlined in more detail in Appendix III, which provides a review of the standard solutions for each type of ventilation failure.

Because houses can fail a Checklist for a wide variety of reasons, there are also many potential remedial measures. A ventilation imbalance, for example, can be remedied by improving a chimney performance, or increasing the make-up air, or reducing the exhaust capacity, or some combination of these strategies. Each strategy will offer a variety of technical solutions, with varying degrees of sophistication. The identification of an appropriate remedial measure, for a particular house, will involve many non-technical factors such as cost, comfort, convenience, and security. For all these reasons, it should be apparent that combustion venting problems are much easier to find, than to fix.

A short list of the priority remedial measures, identified for field evaluations, is presented below. A number of these measures are described in more detail in Appendix IV, (including sketches, technical diagrams, and installation guidelines).

i. Forced and Tempered Air Supply

A fan and duct heater apparatus is an appropriate remedial measure for houses experiencing chimney failure due to high powered exhaust systems (eg. stove fans and range hoods). By using a fan to force air into the house, it is possible to provide a precise quantity of make-up air, when and where required. The fan solves some of the problems of the passive air supply ducts, such as unacceptably large holes in the wall, too much or too little air supply due to wind pressures, and air supply at the wrong times. The fan also offers the potential for pressurizing the house and reversing flow in a chimney experiencing a stable downdraft, something impossible with a passive air supply system. Operation of the supply fan can be slaved to exhaust fan operation, or to chimney temperatures, or the furnace operation, or to the indoor/outdoor pressure difference, or to whatever strategy is appropriate for the house.

Combining the fan with a proportionally controlled duct heater ensures that supply air will always be warmed to room temperature, but not significantly higher. A thermistor control would be mounted downstream of the heater and fan.

ii. Direct Air Supply for Clothes Dryers

Standard-model clothes dryers can exhaust as much as 150 L/s and can constitute a hazard in tighter houses, or in houses with numerous small exhaust systems. Many failure houses could avoid unacceptable depressurization simply by providing a direct outdoor air supply to the clothes dryer.

Installation of a direct air supply system would not be much more complicated than installing a dryer exhaust kit. A metal panel with collar would replace the existing access panel on the lower back panel of the dryer. A flexi-duct hose could then connect the dryer housing with the outdoors, preferably fitted with a two-way damper kit, to avoid air infiltration during off periods. Weatherstripping and aluminum tape could reduce air entry into the dryer from pathways other than the flexi-duct. The dryer would become a balanced ventilation system, and the drying efficiency may even improve because of the drier supply air.

iii. Fail-Safe Devices for Gas-Fired Water Heaters

Gas-fired water heaters are the most common appliance experiencing regular spillage and backdrafting in failure houses. Many householders would appreciate the security of a device that could shut off the water heater rather than permit heavy spillage of combustion gasses. Such a device might be appropriate for all gas-fired water heaters, but would be most useful in tighter houses, where the spillage is a greater threat to air quality, and in houses where the vent/pressure test results are close to the MAD limits.

At this moment, the most cost-effective fail-safe is a thermodisc mounted on the draft hood and wired in series with the thermocouple. Older style water heaters can be fitted with a thermocouple junction, for this purpose. High-temperature combustion gas spillage, around the draft hood, would cause the thermodisc to break the circuit, shutting off the gas valve. Unfortunately, the pilot light must be re-lit before the heater can be operated. The position of a manual reset button, on the thermodisc, would inform the householder whether a pilot light outage had been caused by hazardous spillage.

iv. Alarm Systems for Gas-Fired Furnaces

In some houses, the best way to avoid hazardous spillage, or backdrafting, from a gas furnace is through timely maintenance and judicious operation of ventilation systems. Thus a simple, low-cost, temperature-controlled alarm may be the most appropriate strategy, especially in houses with a history of chimney problems, or where spillage is possible but unlikely, or where the occupants desire extra protection, or where remedial measures would entail unacceptably high costs.

An alarm system, unlike a 'fail-safe' system, would not shut off the furnace in the event of spillage, since this would require more complex and costly controls, to avoid freezing the home when people are absent. Instead, a loud buzzer would alert the occupants that the furnace is operating in a hazardous condition. Presumably, they could assess the situation and, depending upon the severity and frequency of spillage, obtain an expert diagnosis, or modify their operation of the house (for example, open a window to supply air to the fireplace, or clean the fresh air duct filter on the air exchanger).

The alarm could consist of a double throw thermodisc (or solid state thermistor), mounted in front of the dilution air inlet of the furnace and wired in line with the house thermostat. If spilling combustion gasses heated the switch above its set-point, the circuit from the house thermostat to the gas valve would be re-routed through a metal buzzer. As the house thermostat calls for heat, it thus operates both the buzzer and the furnace. The thermodisc could automatically reset, unless for some reason the householder wanted to be informed of every spillage incident.

v. Delayed Action Solenoid Valves for Oil Furnaces

Oil furnaces are less prone to backdrafting and spillage problems because the convention gun-type burner creates a degree of forced draft, through the operation of the squirrel cage fan used for combustion air supply. The fan creates sufficient pressure in the chimney system to overcome almost any downdraft, and may also compensate for poorly designed or partially obstructed flues. Because the fan operation on most oil burners commences only with ignition, there is an initial period of spillage and sooting until the fan pressure stabilizes and good fuel/air mixing and a strong chimney updraft.

The installation of a delayed-action solenoid valve, on the burner, will delay oil flow for the first 6 seconds. This helps to ensure proper draft prior to ignition. Installation of a solenoid valve may be an appropriate remedial measure in houses where the oil furnace fails the vent/pressure or spillage tests, or where heavy sooting is contributing to flue blockage, or where occupants are complaining of odors and fumes.

vi. Direct Air Supply to Fireplace - Through Ash Clean-Outs

The large air requirements of fireplaces are best satisfied by a direct outdoor air supply duct, terminating inside the fireplace opening. As long as the capacity of this air supply duct is sufficient to make-up air lost via the fireplace chimney, the danger of a fire causing flow reversal in the furnace chimney is eliminated. Cold drafts indoors are also avoided. A wood fire will operate well, and at less cost to the householder, using unheated air from outdoors for both combustion and draft. A damper on the air supply duct can avoid unnecessary heat loss when the fireplace is not in operation.

Unfortunately, direct air supply ducts for fireplaces often require hiring a mason to remove bricks from the back of the fireplace, an operation so costly that a cheaper and more appropriate approach may be to replace the open fireplace with a prefabricated wood burner. An exception is a fireplace fitted with a large ash clean-out pit. The pit opens at the floor of the fireplace - the best and safest location for air supply. Converting an ash clean-out to an air supply requires two components: a replacement cover for the hole, containing a raised and expanded opening fitted with a rounded grate (to avoid blockage), plus a damper (to close when not needed); and a louvered duct sloping down into the pit from the outdoors (to prevent sparks from dropping outdoors).

vii. Balancing Forced Air Distribution Systems

A furnace blower is an extremely powerful fan. It often contributes to spillage and backdrafting of flues, because of an imbalanced, leaky, or poorly designed duct system. For example, as the blower moves air through the house, it may exhaust some of the forced air into unconnected areas (attics, garages, crawl spaces, new additions, cold bedrooms). Alternatively, the blower may suck disproportionate quantities of return air from areas adjacent to the furnace or fireplace chimney. Both situations are likely to lower pressures indoors.

The balancing of a distribution system is best accomplished by sealing ducts passing through areas outside the heated envelope, and by sealing the return air plenum and blower compartment next to the furnace. This is often not possible because: 1. it's a difficult and tedious application; and, 2. the ducts responsible for the losses are closed into floors and ceilings, or otherwise inaccessible. A second strategy is to install additional warm air registers, close to the furnace room, and/or addition cold air returns in remote areas. A third and final strategy is to provide an insulated fresh air duct to the cold air return plenum. In any case, the balancing of the distribution system is best accomplished using the Safety Check procedures to monitor the success of the remedial measures.

4.2 APPLICATION OF REMEDIAL MEASURES ON FAILURE HOUSES:

The five regional field evaluators were requested to propose remedial measures for failure houses. In most cases, the application of cautionary labels was sufficient. Additional remedial measures were deemed appropriate in cases where the existing situation appeared hazardous to health and safety of occupants, or where labels were unable to warn against dangerous operating conditions. Proposals were received from three of the five regions.

In the Toronto region, it was felt that, because of the marginal nature of the failures and the low number of failure houses, no additional remedial measures would be required, or could be justified. In the Winnipeg region, a sophisticated air supply system was developed and applied to one of the more serious house failures. In all other Winnipeg houses due to budget restrictions, it was decided to send individualized explanatory letters to occupants of failure houses.

Some of the houses receiving remedial measures, in the British Columbia and Ottawa regions, have been described in the case studies that follow. In each case, the remedial measures represent a consensus decision - involving the regional evaluator, the householder, and Sheltair management. Field evaluations of the measures was a two-part process: application by a licenced contractor, (in the presence of field evaluators); and performance testing of the house by evaluators, using the Safety Check and other appropriate technology.

CASE STUDY HOUSE #30:

This new, two-storey house was included in the R-2000 program. Signs of backdrafting were noticed, by Sheltair staff, during an unrelated research project. A gas furnace and gas water heater are located in the basement, next to an air exchanger. Exceptional features on the furnace included an Ameritherm damper, electronic ignition, and energy-saving cycler.

Failure Description

The house experienced high levels of depressurization (8.5 Pascals), due to an imbalanced air exchanger operating simultaneously with clothes dryer. A problem still existed after opening inlets (5.2 Pascals). The airtight wood stove, with outdoor combustion air supply, was completely unaffected by the low indoor pressures. However, the furnace and DHW spilled continuously, during the spillage check, and exhibited visible signs of backdrafting. Occupants complained of poor air quality in the sewing room adjoining the furnace room.

Proposed Remedial Measures

1. It was proposed to install a damper on the warm side of the exhaust flow of the exchanger, and to balance the air flows, using a hot wire anemometer, with furnace and DHW operating.
2. A second proposed remedial measure was to supply direct outdoor air to the sealed casing of the clothes dryer. The dryer inlet duct (with damper in place) would be located close to the dryer but at least 600 mm from the exhaust outlet.

3. Installation of a buzzer alarm system for the furnace, and a fail safe thermo-disc shut-off for the water heater was proposed to guard against any continuation of spillage.

Evaluation

1. Balancing the Air-to-Air Heat Exchanger:

Balancing of the air-to-air heat exchanger was a simple matter of installing an in-line damper on the 6" diameter exhaust ducting, (see Photo 1). Since the existing design did not permit a warm-side installation, the damper was placed on the cold side. Air flow balancing was completed with a hot-wire anemometer; although a magnahelic pressure gauge was found to work as well. The flow varied consistently plus or minus 5 m/s due to wind and other factors, and this limited the possibilities of perfectly balancing the flows. The process of trying to balance an existing, two-way ventilation system raised a number of questions :

- the intake filter was badly plugged with moths, other bugs, dust and a tarry, wood smoke substance. Should balancing be done with or without cleaning the intake filter?

- the initial variation in flows between the two air streams was greater than 30 %. Since dampering the exhaust flow reduces the total air change in the house - (which is already inadequate when compared to ASHRAE standards) - should an attempt have been made, instead to increase air intake after analyzing, testing and retrofitting the entire ventilation systems?

- in a house with serious backdrafting problems already occurring, and with an airtight envelope, should the ventilation system be balanced to provide 2 or 3 Pascals of pressurization? (This approach would provide a margin of safety in the event, say, of a dirty filter, a more powerful dryer exhaust, or summertime use of the DHW heater.)

- prior to balancing the ventilation system it is crucial to check all outlets and intakes, to ensure they are clean and fully open.

Exhaust intakes in the washrooms often have manual dampers; the exhaust outlet may even be plugged or taped by the householder - a problem encountered in House #30. Should balancing a potentially hazardous system also entail labelling the intakes and outlets with cautions about potentially unsafe operating conditions (if applicable)?

- the fresh air from the exchanger spilled into the cold air return plenum of the furnace. The furnace did not have a 2 speed blower. Operation of the blower increased the velocity of intake air by 7 to 8 m/s. Should the system be balanced with blower on, or off?

2. Fail-Safe on DHW:

The installation of the fail-safe device on the DHW heater was found to work well. Photo 2 shows the new thermocouple junction below the gas valve. The wires from the junction connect through the manual-reset thermodisc fixed to the draft hood, (see Photo 3). Installation required about 15 minutes. The thermodisc consistently shut off the burner within 33 seconds, following a cold start with the flue connector blocked. Minor spillage at start up (due to slow opening of the vent damper) did not cause the thermodisc to break contact.

3. Alarm System on Furnace:

An automatic reset thermodisc (120-140%F) was mounted in front of the dilution air inlet and wired in series with the house thermostat and a 24 volt metallic buzzer, (see Photo 4). Installation of the alarm system required over an hour due to complications. The system did not work as intended, because the furnace was equipped with an electronic ignition and an energy-cycler. The electronic ignition would not operate simultaneously with the buzzer. Consequently, the alarm system had the effect of shutting off the appliance when the flue was blocked or backdrafting. Buzzing would continue until the thermodisc cooled. After intentionally blocking the flue, a typical cycle consisted of 10 seconds operation (with spillage), 35 seconds of buzzing with no operation, and repeat.

Minor spillage continued to occur with the flue unblocked, due to a design flaw in the flue connector. Unfortunately the partial spillage did not succeed in activating the alarm.

4. Clothes Dryer Air Supply:

Because a clothes dryer air supply is drawn through the perimeter of the drum, the only way to control the supply air is to seal the entire exterior of the appliance, and feed air through the back. To test the practicality of this technique, a direct air supply kit was prepared and evaluated, prior to commencing work on House #30. The kit consisted of weatherstripping, aluminum tape, a dryer exhaust kit, and a short piece of 10 cm (4 inch) metal duct with flange. The front, top and back of a conventional clothes dryer were removed and weatherstripped, and a 10 cm (4 inch) diameter hole has cut through the lower back access panel, (see Photo 5). The panel and exterior pieces were replaced, all remaining leakage areas taped with aluminum duct tape, and a flexible dryer hose connected to the new hole, (see Photo 6). A hot wire anemometer was then used to measure air flow into and out of the dryer through the flexi-ducts. Average exhaust measured 4.5 m/s (or 38 l/s), and the intake 3 m/s (or 25 l/s). The direct air supply duct was providing 2/3 of the dryer air requirements, (with the remainder presumably entering through unnoticed cracks and openings).

Since the concept of direct air supply to a dryer appeared workable, a second dryer air supply kit was prepared for House #30. The proposed retrofit was aborted, however, after trying to balance the air-to-air heat exchanger. Because minor variations in operation of the air exchanger (e.g. cleaning filters, furnace operation) had much greater effect on house pressures than the dryer, it seemed pointless to bother with the dryer. Pressurization of the house, on a continuous basis, by the air exchanger, was felt to best compensate for dryer operation.

5. Safety Check Repetition, and Flue Connector Sealing:

A repeat of the Safety Check indicated a failure still existed in House 30, even after the retrofit measures, due to continuous spillage from the furnace dilution air inlet. Investigation revealed a major problem with the installation of the flue. The Lenox 55,000 BTU furnace had a 10 cm diameter collar which was connected directly to a 13 cm diameter flue. A 10 cm to 13 cm expanding connector had been left out by the installer, for unknown reasons. A 15 mm gap, around the outside rim of the furnace collar, opened into an air space above the overflow vestibule and allowed the flue to draw mostly basement air, instead of combustion gases. The result was a major short circuit of the flue.

The gap around the flue collar was temporarily sealed, using high temperature flue tape, and the householder was advised to contact his installer. A repeat of the Safety Check passed the house.

CASE STUDY HOUSE #31

A 3 year old, two-storey house with a heated crawl space. This house has a large number of exhaust systems (10), and a down-flow gas furnace. Occupants had suffered health problems from a backdrafting furnace and the house had been included in the 1984 CMHC backdraft research (ref.3).

Failure Description

At 8.4 Pascals, the fans and blower operation exceeded allowable depressurization limits, even with two make-up air-supply routes unsealed. The fireplaces required an enormous make-up air supply area. All systems required labels and the house was a good example of multiple failures. The most serious problem was the furnace blower, which created high levels of depressurization, in both low and high speed operation.

Proposed Remedial Measures

Measures were proposed to incorporate the crawl space into the heated envelope of the house, there-by preventing the blower from acting like an exhaust fan. Also, the distribution system would be tightened and balanced, to prevent the loss of so much warm air into the crawl space.

A combustion air supply would be provided, directly to fireplaces, by converting the existing ash clean outs to air supply inlets, with grills and dampers.

Because of the complex failures, and the many remedial measures, a fail safe system would be installed on both the furnace and the DHW heater, and an alarm system on the furnace.

Evaluation

Crawl Space Duct Losses:

Balancing the air distribution system proved to be a difficult task. A manometer was used, as per the Safety Check procedures, to monitor the success of relief measures. Initially a window was opened to determine the size of free area required to make- up for the duct losses. An opening of 0.3 square meters managed to reduce house pressures to approximately zero, (see Photo 7). Since installing a permanent air inlet of this size would be uncomfortable and enormously costly for the householder, the only viable solution was to eliminate the crawl space duct losses.

All of the duct joins and registers in the crawl space were carefully sealed with aluminum duct tape (Photo 8). Crawl space vents in the four foundation walls were plugged with beadboard (Photo 9). These measures reduced the furnace room depressurization from 8.5 pa to 4.5 pa.

A hole was cut into the plywood trap door of the crawl space, and fitted with a grill to permit air movement from the crawl space back into the furnace room. Pressures dropped from 4.5 pa to 3.5 pa.

An additional return air duct was cut through the floor, near the furnace, into the crawl space, to further reduce air losses, (Photo 10). Pressures dropped again from 3.5 to 2.0 pa. No further pressure reductions were achieved. Eight man-hours were required for these crawl space measures.

Fail Safes and Alarms:

Thermodiscs were mounted near the dilution air inlet openings of both the furnace and the water heater, and wired so as to shut off the appliances, in the event of heavy spillage. A buzzer was wired in series to the furnace thermodisc, to alarm the householder in the event of failure. Both system appeared to work as intended, shutting off the appliances within one minute of operation following blockage of the flue.

A problem was encountered with relighting the pilot on the water heater because the thermocouple millivolt output seemed insufficient to keep the valve open with the added resistance of the thermodisc wiring. However, a measurement of the thermocouple output showed 18 mv, and the problem was eventually solved by carefully re-soldering all connections, and providing the pilot with a full three minute warm-up before releasing the manual (red button) valve.

CASE STUDY HOUSE #32:

This is a 1960, one-storey house with an above-grade basement. A gas-fired furnace and DHW heater share a utility room with an exhausting dryer. The house was assumed to be relatively tight and is presently undergoing an interior storm window retrofit. Two well-used wood fireplaces are a potential source of problems.

Failure Description

The house failed the furnace room vent pressure test, at 6 Pascals, and the spillage check also failed. Even though labels were applied, concern was felt over the worsening affect that the ongoing window retrofit would have on the available make-up air supply, for both furnace and fireplaces. The fireplace in the basement does not have an easily-accessible, openable window.

Proposed Remedial Measures:

It was proposed to install additional make-up air supply to the house. The stand-by heat loss from the water heater would be used to temper fresh air as it spills from a 150mm diameter horizontal duct. Air would be drawn through the horizontal duct when ever a pressure difference existed between indoors and outdoors. A finely adjusted barometric damper, positioned in the duct near the exterior wall, would help to dampen high velocity flows due to wind gusts. The duct would be insulated against heat loss, and would be mounted with an air conditioning diffuser, to maximize mixing and tempering.

Evaluation:

The configuration of the installed air inlet is illustrated in Photos 11 and 12 (inside and outside). Material costs amounted to $72, and installation required three-and-a-half hours at $32 an hour, amounting to a total bill of $184.

A repeat of the Safety Check, following installation, showed that the effect of the inlet was to reduce house depressurization by approximately 1 Pascal. This was sufficient to allow the house to be operated safely according to the M.A.D. limits (exhaust fan operation only). The operation of fireplaces would still require additional air inlets and labels were left on.

A smoke pencil was used, during the Safety Check, to determine the air flow patterns emerging from the air inlet. The use of the air conditioning diffuser resulted in a rapid mixing and tempering of the air, as intended. The exit velocity from the diffuser increased due to operate of exhaust equipment, but some amount of air movement could be detected even under calm conditions and without exhaust equipment operating. The direction of fresh air movement was still predominantly away from the exterior wall despite the circular diffuser. (An improved design might entail a dead end buffer, in the horizontal duct, to avoid the velocity pressure skewing the air entry patterns.

It was hoped that the circular diffuser would move fresh air in a relatively horizontal direction, upon entering the room, but, at best, the angle of entry was about 30% from the horizontal. Although the air was well-tempered, due to the mixing patterns, much of the fresh air was, in fact, dropping slowly to the burner intakes of the hot water heater and furnace, during operations, and was thus being used for combustion and draft purposes. The householder claimed to experience no problems or discomfort with operation of the air inlet, over the three-week period in December following the installation.

The barometric damper installed in the inlet duct was found to prevent gusts of wind from entering the inlet duct. It was possible to cause the damper to close off the duct temporarily just by blowing hard with the mouth, from a distance of one metre outside the house. The sensitivity of the barometric damper to wind gusting showed excellent potential for this kind of application, but some measures should have been taken to ensure continued flow through the duct, even with damper shut (e.g. a safety hole in the damper itself).

CASE STUDY HOUSE #36:

Built in 1940, the house has one storey, with an above-grade finished basement. The householder had complained about the oil furnace back-puffing smells, during operation of a kitchen stove-top fan. The house had been comprehensively air-sealed, by occupant, and an extra fan had recently been added to bathroom, to control humidity problems. Due to spillage problems, the occupant has abandoned use of an open wood fireplace.

Failure Description:

House failed the furnace room and fireplace vent pressure test at 6 and 4.7 Pa respectively. The flue connector of oil furnace was half full of soot - presumably caused by regular back-puffing caused by the constant down drafting in the interior furnace chimney. The oil furnace, lacking a barometric damper, may have been prone to very sooty start-ups.

Proposed Remedial Measures:

It was proposed to interlock the stove-top fan with the oil furnace. This appeared to be the easiest solution to preventing simultaneous operation. Operation of the fan would power a relay switch and break the thermostat line.

To prevent back-puffing at start-up, a delayed action solenoid valve was proposed. By preventing a flow of oil during the first 6 seconds of burner fan operation, the valve might help to ensure a strong updraft at time of ignition.

No remedial measure was proposed for the fireplace. Supplying a large outdoor combustion air opening, to an interior fireplace, presented major technical design difficulties.

Evaluation

1. Interlocking Fan and Furnace:

A 110 - 24 volt relay switch was mounted inside a bakelite box, and then wired to the thermostat and to a barbecue fan, from a location inside the joist area of the basement ceiling (see Photos 13 and 14). Material costs were $41. Problems encountered with obtaining the proper relay switch, and with fishing the thermostat wire through the finished basement ceiling, resulted in an extended installation time of four hours. (Under ordinary conditions, one or two hours would seem more likely.)

The interlock was tested and found to work well, immediately. However, two weeks after installation, the householder informed the installer that the system no longer functioned. The problem was discovered to be a faulty relay switch which was replaced.

Interlocking the stove-top barbecue with the thermostat line worked especially well, because it did not cut power to the furnace blower. If the furnace was operating at a time, when the stove top fan was turned on, the oil burner might be temporarily shut off, but the furnace blower would continue to operate and circulate residual heat throughout the house.

2. Delayed-Action Valve:

The delayed action solenoid valve is illustrated in Photo 15. The installation is relatively straightforward, with a 30 minute installation time, and $64 material cost. The valve worked as intended; the squirrel cage blower in the oil burner could reverse downdrafting prior to ignition. The total pressure, generated by the burner fan, was measured at the breach, with the flue plugged. The pressure would rise in spasms, to 30 or 35 pascals before ignition. Oil burners with delayed action valves would thus appear to be effective at establishing updraft in a chimney - as long as an imbalanced barometric damper does not short circuit the system.

One problem encountered was a very brief flame and smoke at start-up, due to a small amount of oil siphoning downstream of the valve. It was not possible to determine whether this was a design flaw, or some fault with the particular valve, pump and oil-line system being tested.

CASE STUDY HOUSE #1:

House 1 is a two-storey detached modern home, with a gas-fired forced- air furnace and two wood fireplaces.

Failure Description:

Multiple failures were experienced. A failure pressure of 6 Pascals was recorded for the furnace room, and 3.5 Pascals for the fireplace room. The spillage check showed spillage for more than 15 seconds. The requirement for additional remedial measures is particularly important for House #1, since the occupants have already experienced ventilation problems and have suffered from carbon monoxide poisoning.

Photographs 16, 17 and 18 illustrate the geometry of the flue connector. The furnace flue takes two 90% bends, has a 1.5 metres straight run, and is joined by the DHW flue, just before the thimble. It continues within the wall, horizontally, for another 0.5 metres. It is felt that the design of this chimney contributes to the poor draft characteristics.

Proposed Remedial Measures:

A draft reducer kit would have been an appropriate remedial measure for this house, since it could ensure strong updraft under all operating conditions. However, the cost and complexity makes it an impractical choice. As an alternative, it was proposed to install a buzzer alarm system on the furnace, and a fail-safe system on the hot water heater.

CASE STUDY HOUSE #2:

House #2 is split-level, detached, modern home with gas-fired forced-air furnace, gas water heating, a wood fireplace and 3 exhaust fans.

Failure Description:

Furnace room depressurization of 3 Pascals produced a marginal failure. The fireplace room depressurization of 3.5 Pascals represents a more serious problem. Backdraft was witnessed during testing, and the fireplace has a history of poor draft. (The chimney had failed during the backdraft testing in January 1984).

Photograph 19 illustrates the exterior geometry influencing draft on the flue for the furnace and hot water heater. The flue extends only 1.5 m above the roof. Poor draw on this flue is possibly influenced by an extremely low height, and by its location close to the peak roof and termination well below the eave level of the two-storey portion on the split level house.

Proposed Remedial Measures:

It was proposed to try to improve overall draft in this flue by extending the height. An additional section of 1.5 metres would be installed and supported by means of guy wires attached to the roof.

Evaluation:

Photograph 24 shows the flue with an additional 1.6 meter extension. (The new extension had not yet been guyed due to heavy ice formation on the roof.) A total pressure measurement of the flue draft was taken before and after the installation. Measurement procedures entailed the temporary sealing of the furnace flue, and a static pressure reading of the flue draw versus furnace room pressure at a point in the flue below the DHW junction. Data is summarized below:

Jan 7 (before installation):
Temperature Outdoors at -16° C. Winds NW @ 22 kph. Draft fluctuating between 5 and 7 Pascals.

Jan 9 (after installation):
Temperature Outdoors at -16° C. Winds W @ 22 kph. Draft fluctuating between 9 and 11 Pascals.

Although the windy test conditions probably served to exaggerate the impact of the flue extension, the increase of 4 Pascals, in total chimney pressure appears to have successfully generated the necessary safety margin required by this house.

CASE STUDY HOUSE #3:

House 3 is a detached, two-storey, modern house, with a gas-fired forced-air furnace, gas hot water heating, a single wood fireplace, and 4 mechanical exhaust fans.

Failure Description:

The house failed the furnace room vent pressure test at 5 Pascals, and the fireplace room depressurization at 3.5 Pascals. Worst case conditions achieved a maximum depressurization of 7.5 Pascals. This Apple Hill house had already experienced considerable difficulty in operation of the furnace room; the room is too cold if the door is shut, but if the door is open, the room becomes a potential backdraft hazard.

Photograph 20 illustrates the ceiling and back wall of the furnace room. The air supply inlet vent, upper left, is round and stuffed by the homeowner. A rectangular combustion supply vent, (behind the DHW) dropped to about 0.5 metres from the floor, and has been left open to date.

Proposed Remedial Measures:

The householder had purchased a 5 inch diameter motorized damper kit ($90), and was considering installation of this motorized damper on the ventilation air inlet. Appropriate remedial measures for this house might include smaller air supply and motorized dampers, but because of the current legal controversy over Apple Hill furnace rooms, and the proposed remedial measures soon to be undertaken by the builder, it is felt that any proposals for remedial measures should be channelled through the builder, and monitored along with other retrofit work conducted on the subdivision.

CASE STUDY HOUSE #12:

This is a detached, one-and-half storey 1968 house, with an oil-fired forced-air furnace and electric water heating. The house has a single, wood fireplace and 3 mechanical exhaust fans.

Failure Description:

The house failed the furnace room depressurization marginally, at 4 Pascals, and the fireplace room depressurization more, seriously, at 6.7 Pascals. The maximum mechanical and fireplace exhaust depressurization was 6.9 Pascals. The householder has already experienced problems in the home, with poor draft. Photograph 21 illustrates the design of the open fireplace and the surface staining caused by smoke spillage.

Proposed Remedial Measures:

The householder has already undertaken to disable the kitchen fan, during winter time, to prevent cold backdrafting. The householder has also installed a dryer vent diverter, for use during the heating season. The house remains an excellent candidate for a fireplace air supply, or other measures to avoid fireplace backdraft. Evaluation estimates have been obtained for enclosing and venting the fireplace, but the only firm estimate was $1000. This work included installation of doors (over $300) and installation of a dampered air intake ($50 materials plus $300 or more in labour). Because this type of job involves custom work, contractors were unwilling to set a firm price, unless it was extremely high. The high costs raise questions about the practicality of such a remedial measure for any failed fireplace.

CASE STUDY HOUSE #17:

A detached, two-storey, 1982 house with a gas-fired forced-air furnace, a gas hot water heater, and a single, wood fireplace. The house has 4 mechanical exhaust fans.

Failure Description:

The house was a marginal failure, with 3 Pascals depressurization in the furnace room and 5 Pascals depressurization in the fireplace room. The maximum depressurization of furnace room under worst case conditions, was 5.2 Pascals. This house is a typical new home design, and thus represents an interesting case for remedial measures.

Proposed Remedial Measures:

It was proposed to install an alarm on the furnace and a fail-safe system on the hot water heater, as a way of monitoring the incidence of spillage or backdraft in the home, and as a way of protecting the occupants from any serious pollutants.

CASE STUDY HOUSE #18:

A duplex of two-storeys, built around 1960. The house has a gas-fired forced-air furnace, an electric water heater, a wood fireplace and 3 mechanical exhaust fans.

Failure Description:

The house experienced multiple failures, with excess spillage occurring during the spillage check, and 3.5 Pascals of depressurization in the fireplace room. The spillage from the flue represents the more serious failure, since it appears to be continuous and may be related to the flue design. Photographs 22 and 23 illustrate the design problems, with the flue connectors. The spaghetti-like layout of the flue, the location of a barometric damper, a low slope, long run, and the connection of two hot water heaters to the furnace flue connector, all exacerbate low draft and spillage potential. Moreover, the flue connector travels horizontally, inside the wall, for about 1 metre, before connecting with the vertical chimney. The furnace is a converted oil furnace. Spillage was observed out the top half of the dilution air inlet.

Proposed Remedial Measures:

It was apparent that the flue design needs to be laid out in a simpler and more effective fashion. Ottawa Gas was informed of this situation and undertook appropriate measures to improve the flue connector layout. Since the work was to be undertaken by a contractor, on behalf of Ottawa Gas, it was proposed to monitor this work, and repeat the combustion safety check, to evaluate the effectiveness of any remedial measures.

Evaluation:

The new flue design was much straighter (although still twisty). A repeat of the Safety Check Spillage Test was conducted on the new system. Under maximum depressurization (2 fans, dryer, and fireplace) and with the furnace operating, there was no discernable spillage occurring at the barometric damper. Since spillage had been most pronounced at this location, during the original testing, the remedial measure was deemed successful.

5. REFERENCES

1. Hatch Associates Ltd., HAZARDOUS HEATING AND VENTILATING CONDITIONS IN HOUSING, November 1983, Prepared for: Canada Mortgage and Housing Corporation.

2. White, J., IDENTIFYING VENTILATION TROUBLED HOUSES, (Draft), 1984, Canada Mortgage and Housing Corporation.

3. Sheltair Scientific Ltd., RESIDENTIAL CHIMNEY BACKDRAFT CHECKLIST: Design and Evaluation, February 1984, prepared for: Canada Mortgage and Housing Corporation.

4. Hayden, A.C.S., POTENTIAL PROBLEMS, SOLUTIONS AND R&D NEEDS FOR CHIMNEYS, VENTS AND FLUES IN CANADA, November 84, Canadian Combustion Research Laboratory, Energy Mines and Resources Canada.

5. Cogeneration/Par Shelter/ Retrospectors Inc., THE STUDY OF FURNACE ROOM DESIGN AND OPERATION IN APPLE HILL HOMES, Octobre 1983, Prepared for Canada Mortgage and Housing Corporation.

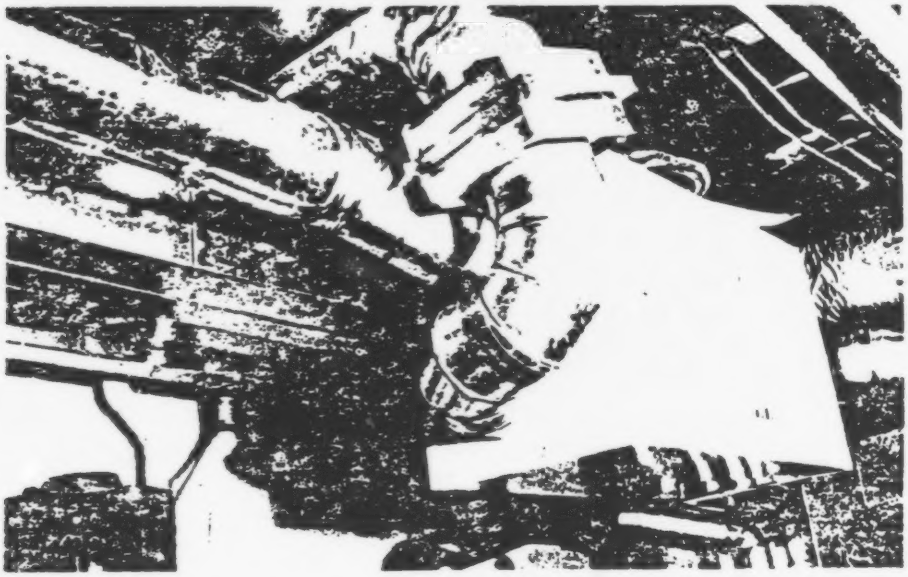
6. Canadian Gas Association, NATURAL GAS APPLIANCE INSTALLATION MANUAL, Fourth Edition, 1976.

7. Wank H., Hay R.L., HEAT EXCHANGER CYCLIC TEMPERATURE RESEARCH PROJECT, February 1970, Canadian Gas Association.

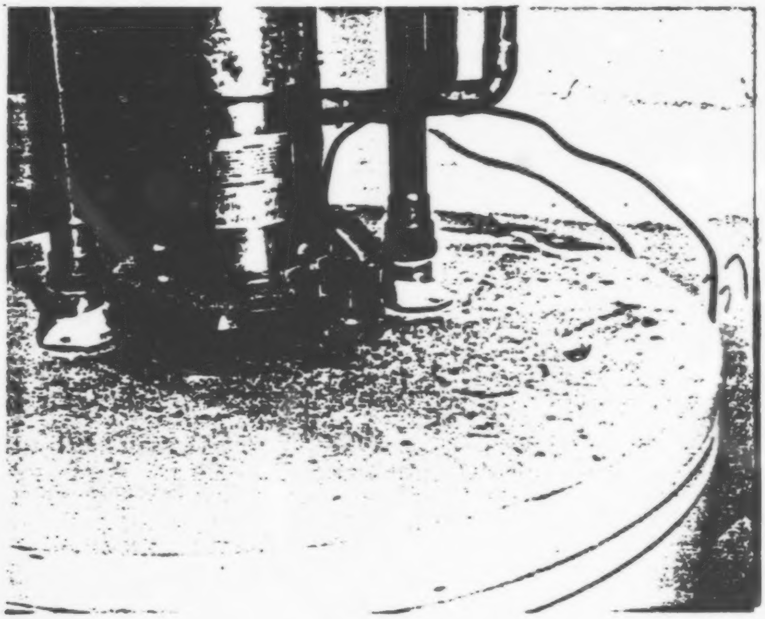
8. Scanada Consultants Ltd., THE THERMAL AND AERODYNAMIC PERFORMANCE OF CHIMNEY FLUES, (draft) August, 1984.

PHOTOGRAPHIC ILLUSTRATIONS OF REMEDIAL MEASURES ON FAILURE HOUSES

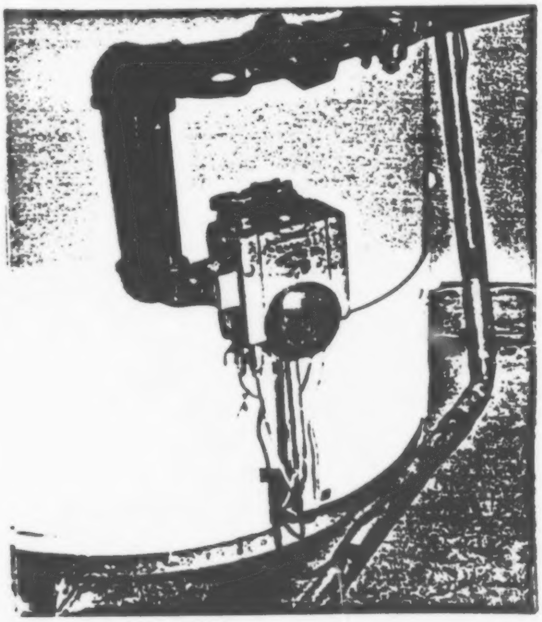
1. Damper installation on air exchanger exhaust ducting (House 30).



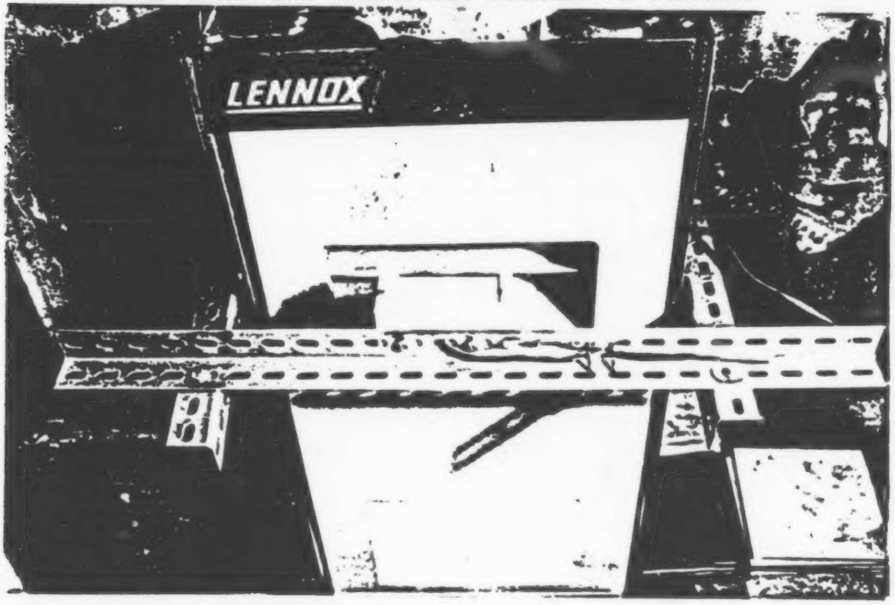
2. Manual reset thermodisc mounted on DHW hood.



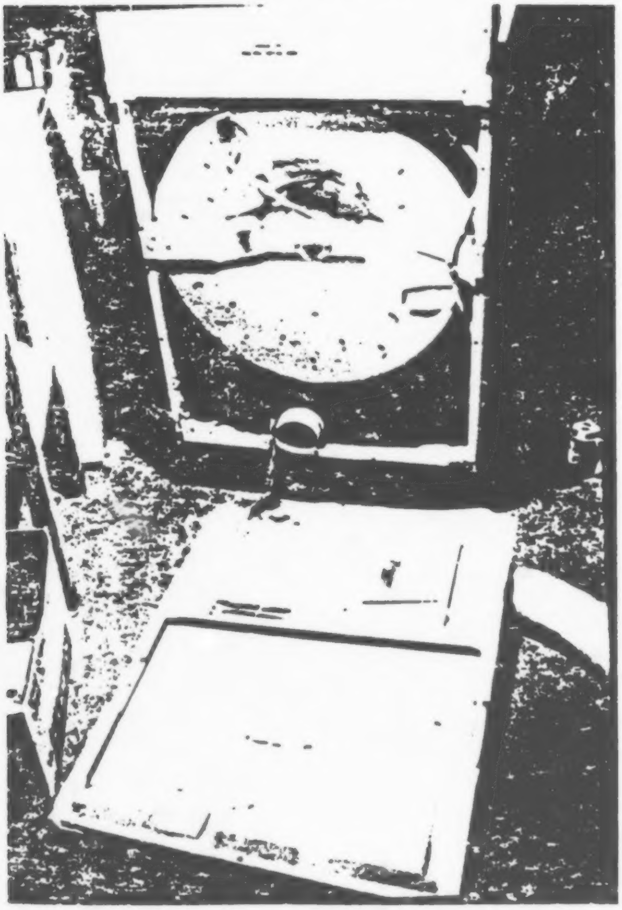
3. Thermocouple junction and wiring below gas valve of DHW heater.



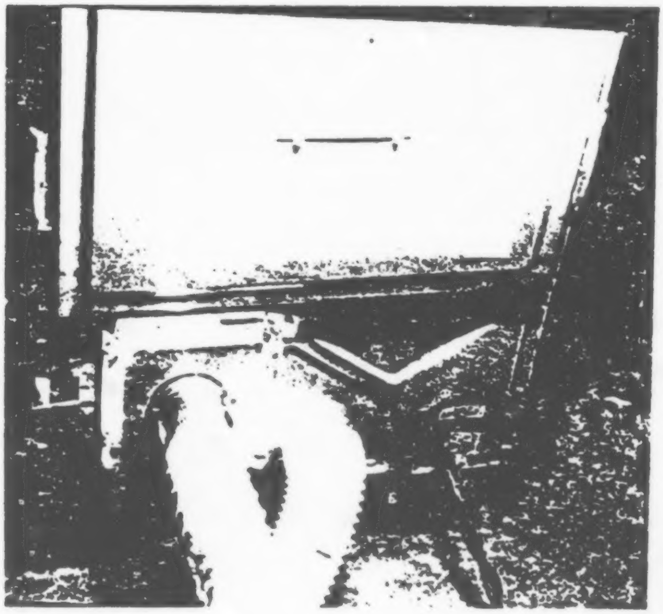
4. Buzzer alarm and thermodisc mounted on furnace.



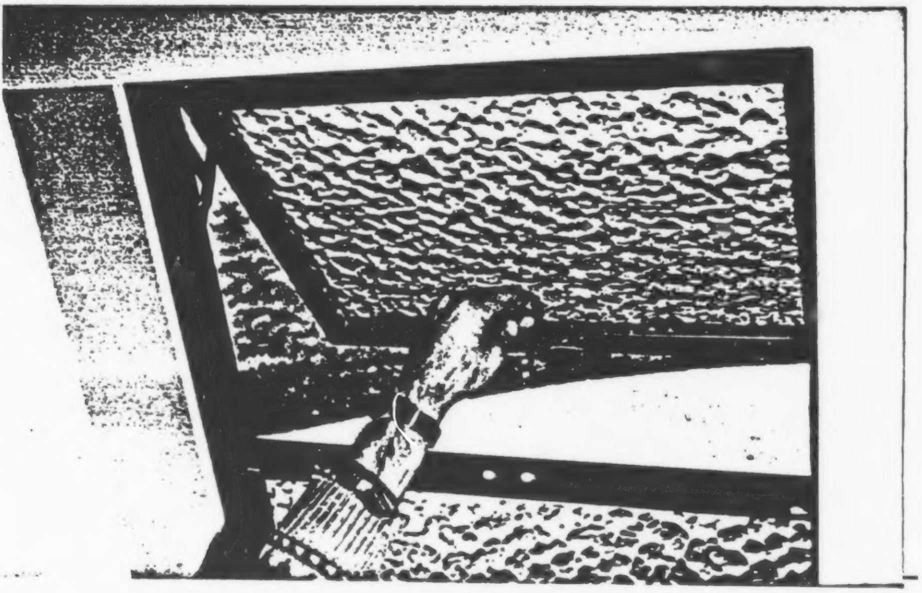
5. Installation of weatherstripping and dryer air supply kit.



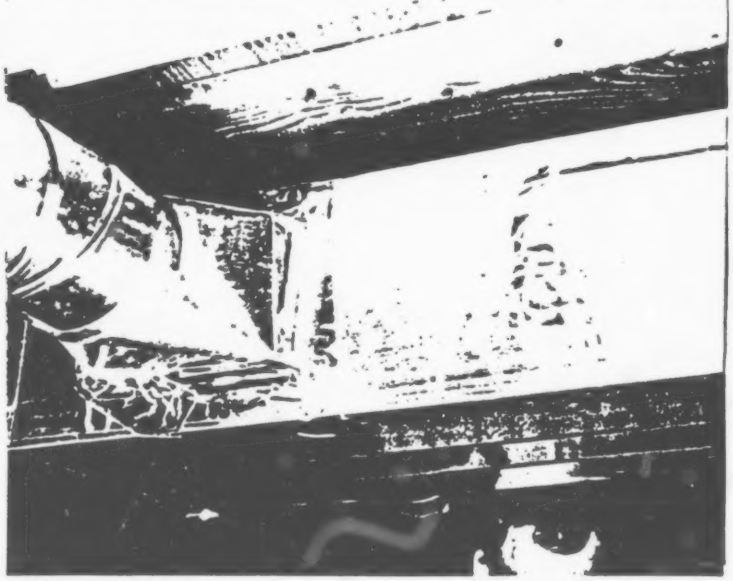
6. Intake and Exhaust hoses on Dryer.



7. Open window area required to balance ventilation, (House 31).



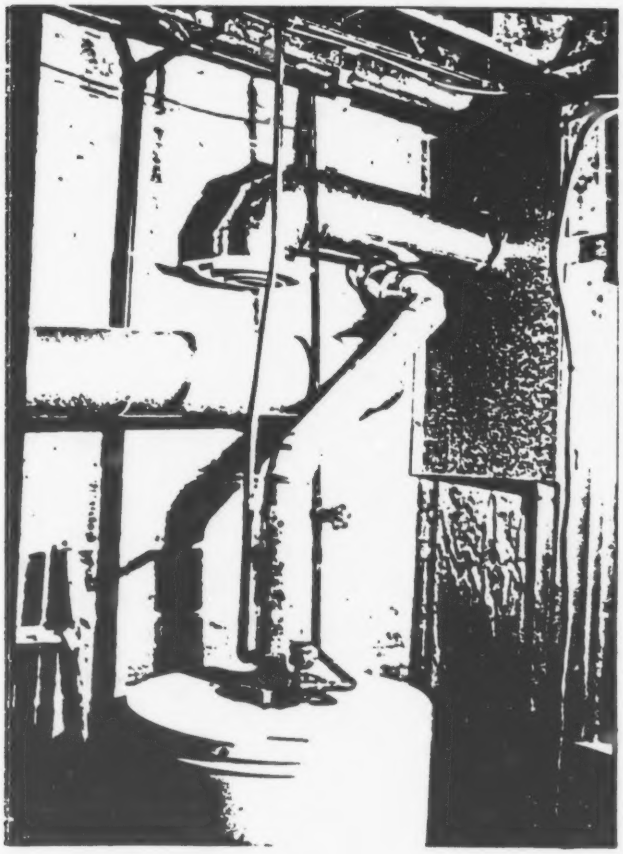
8. Duct sealing in crawl space using aluminum tape.



9. Plugging crawl space vents in band joist using beadboard.

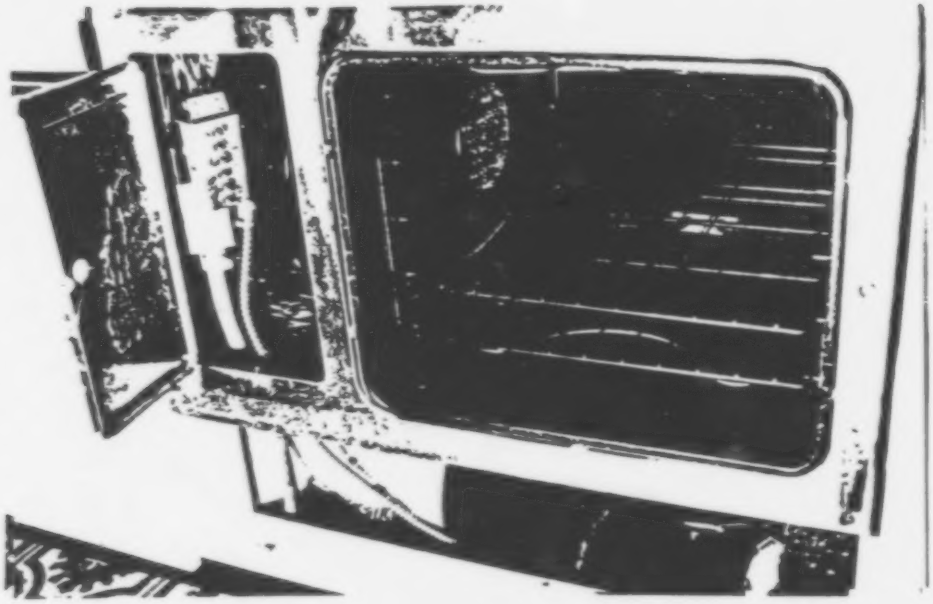
10. Installation of additional return air duct next to warm air plenum.

11. Passive 150 mm air supply duct with diffuser mounted above water heater.



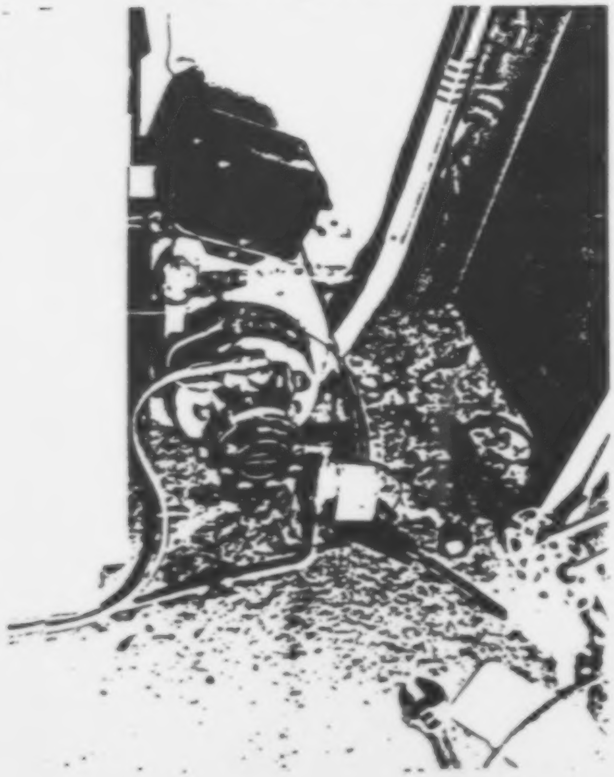
12. Intake from supply duct with barometric damper swinging closed.

13. Wiring conduit beneath oven connects Jennaire fan with relay.

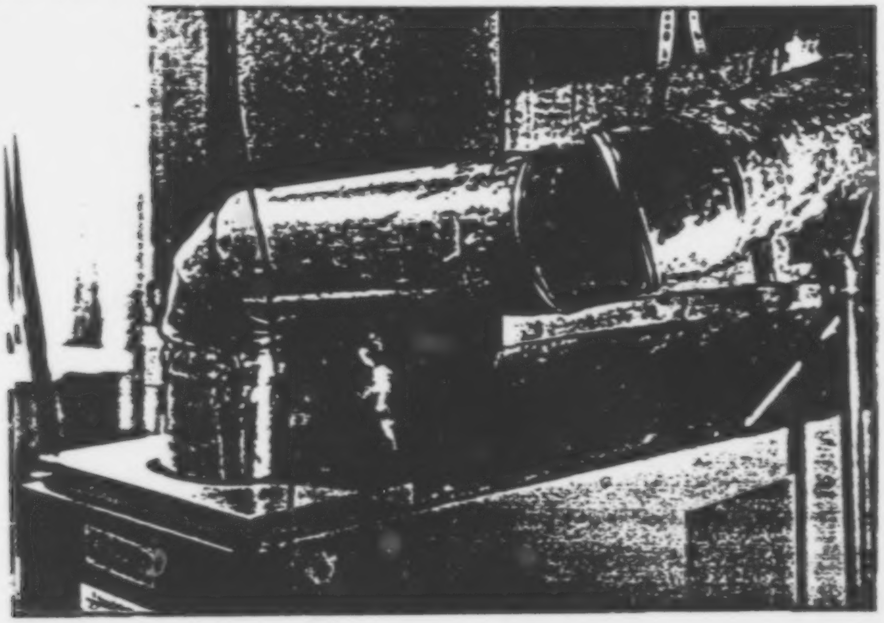


15. Delayed action solenoid valve on oil line to burner.

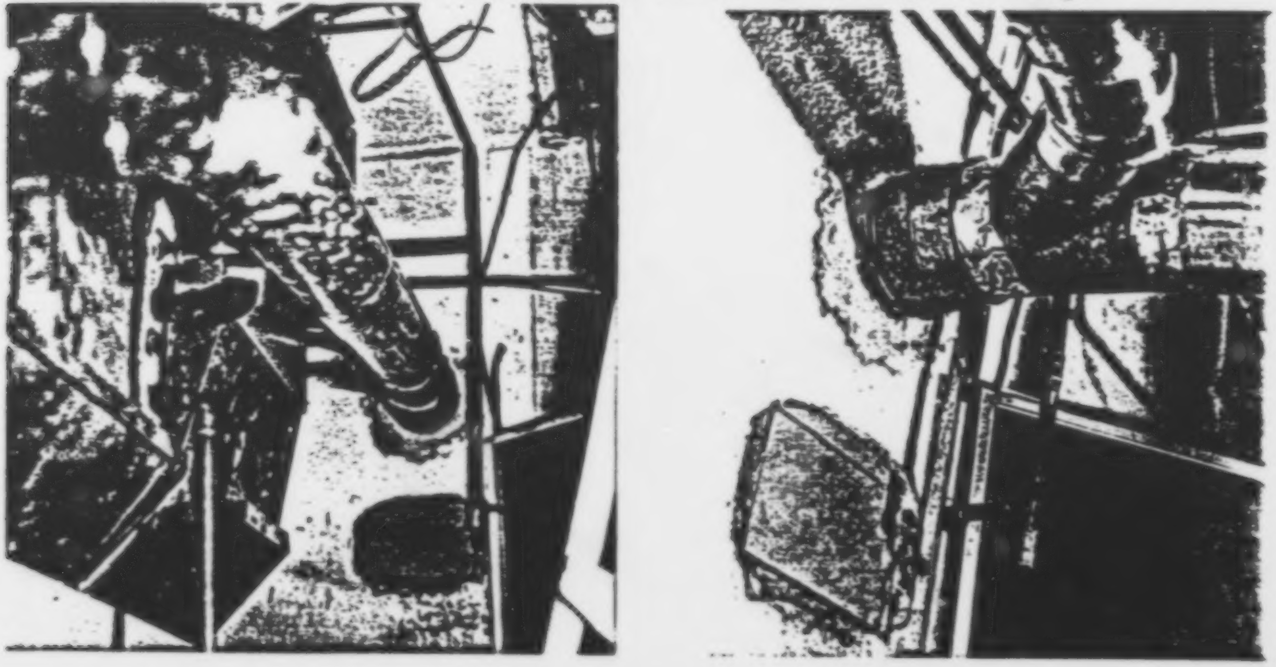
14. Bakelite box containing 110-24 Volt relay interlocking stove fan and thermostat.



16. Two 90° bends in flue connector, (HOuse 1).

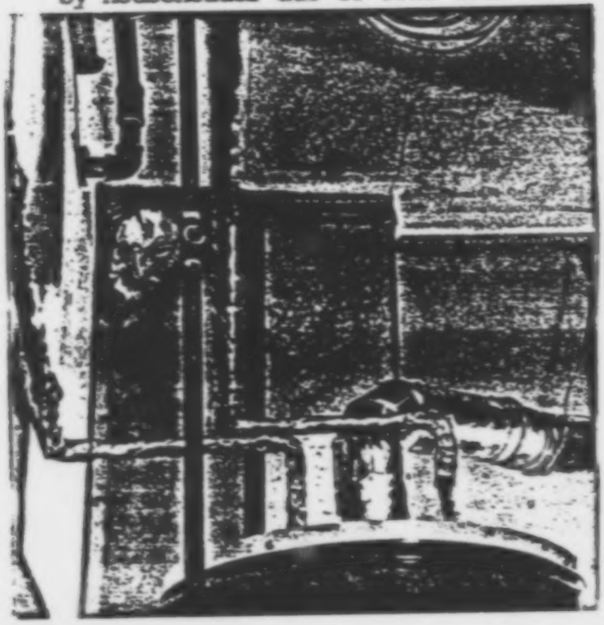


17 & 18. More design flaws in flue connector of House 1, (too long, slope too low, pipe sizing past junction too small, and fittings too leaky).

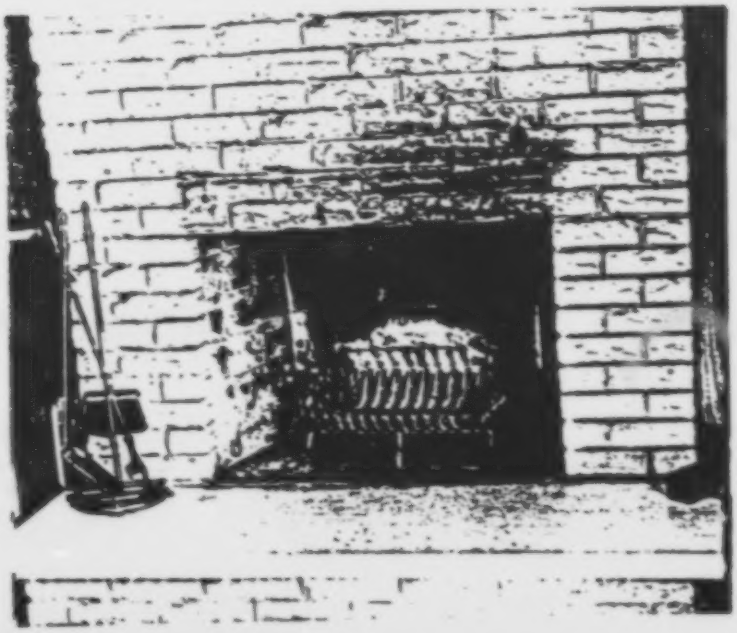


19. Inadequate chimney height on House 2 prior to extension.

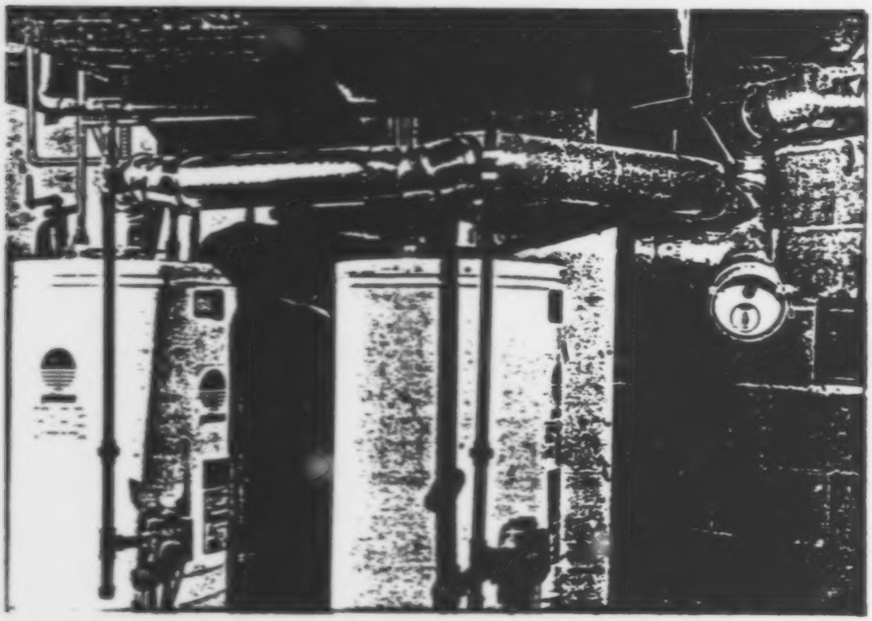
20. Passive air supply duct plugged by householder due to cold drafts.



21. Open fireplace in House 12 shows staining from spillage.



22. Two water heaters connecting to furnace flue.



23. Convolutions in the flue design contribute to spillage failure.

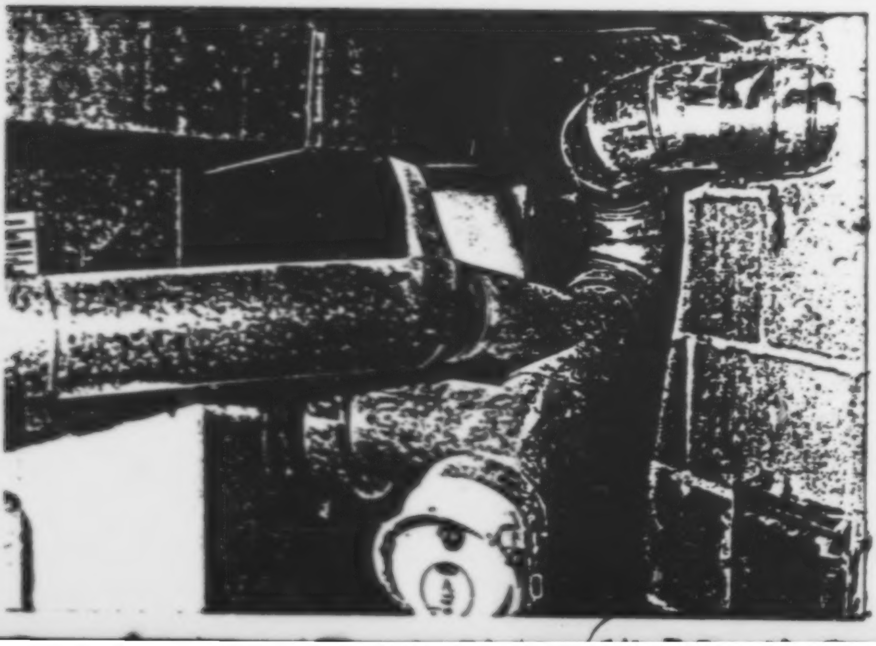


TABLE 1 HOUSE DESCRIPTION - OTTAWA

HOUSE ID	STYLE OF HOUSE *	NO. OF STOREYS **	DATE OF CONSTR-UCTION ***	FOOR AREA (m^2)	PREVIOUS VENTILATION PROBLEMS?	HEATING SYSTEM			DHW HEATER FUEL	FIRE PLACE		NO. OF FANS
						FUEL ****	DISTR. SYSTEM	AGE (YRS)		#1 FUEL	#2 FUEL	
1	DET	2.0	Post 1960	240	poor fpl,CO poison'g	GAS	AIR	0-5	GAS	WOOD	WOOD	4
2	DET	SPLIT	Post 1960	245	poor fpl, backdraft	GAS	AIR	5-10	GAS	WOOD	-	3
3	DET	2.0	Post-1960	250	O/S vents in furn rm	GAS	AIR	0-5	GAS	WOOD	(3) -	4
4	DET	2.0	Pre-1920	185	high humidity	OIL	(1)	>10	ELEC	-	-	2
5	DET	2.0	Post-1960	230	none	GAS	AIR	0-5	GAS	WOOD	-	5
6	DET	2.0	Post-1960	200	none	GAS	AIR	0-5	GAS	WOOD	-	4
7	DET	2.0	Post-1960	250	furnace room	GAS	AIR	0-5	GAS	-	-	4
8	DUP	2.0	Post-1960	175	poor fpl	GAS	AIR	>10	GAS	WOOD	-	4
9	DUP	2.0	1974	200	pilot burns out	GAS	AIR	>10	GAS	WOOD	-	3
10	ROW	2.0	Post-1960	175	none	GAS	AIR	5-10	GAS	WOOD	-	2
11	ROW	2.0	Post-1960	190	none	OIL	AIR	>10	ELEC	WOOD	-	3
12	DET	1.5	1968	175	poor fpl	OIL	AIR	>10	ELEC	WOOD	-	3
13	DET	1.0	Post-1960	200	none	OIL	AIR	>10	ELEC	WOOD	-	3
14	DET	1.0	1971	200	odours	GAS	AIR	>10	GAS	WOOD	-	2
15	DET	2.0	Post-1960	175	none	OIL/WD	AIR	0-5	ELEC	WOOD	WOOD	3
16	DET	SPLIT	1967	250	backdrafting	OIL	AIR	>10	ELEC	WOOD	-	1
17	DET	2.0	1982	150	none	GAS	AIR	0-5	GAS	WOOD	-	4
18	DUP	2.0	Post-1960	175	back-puff,poor fpl	GAS	AIR	0-5	ELEC	WOOD	-	3
19	DET	2.0	1982	250	fpl backpuffing	GAS	AIR	0-5	GAS	WOOD	-	2
20	DET	SPLIT	1946-60	(2)	DHW pilot blows out	GAS	AIR	>10	GAS	-	-	2

Notes:

(1) Whether appliance is forced air or a boiler is not known.
(2) The floor area of this house is not known.
(3) Dash line stands for no fire place.

TABLE 2 HOUSE DESCRIPTION - BRITISH COLUMBIA

HOUSE ID	STYLE OF HOUSE *	NO. OF STOREYS **	DATE OF CONSTR-UCTION ***	FOOR AREA (m^2)	PREVIOUS VENTILATION PROBLEMS?	HEATING SYSTEM			DHW HEATER FUEL	FIRE PLACE		NO. OF FANS
						FUEL ****	DISTR. SYSTEM	AGE (YRS)		#1 FUEL	#2 FUEL	
21	DET.	1.5	1921-45	150	NONE	GAS	AIR	0-5	GAS	WOOD	WOOD	3
22	DET.	1.5	1921-45	200	ODOURS/FUMES	GAS	AIR	0-5	GAS	WOOD	-	1
23	DET.	SPLIT	1970	170	NONE	GAS	AIR	5-10	GAS	WOOD	(1) -	2
24	DET.	1.0	1921-45	120	ODOURS/FUMES	GAS	AIR	>10	GAS	WOOD	-	2
25	DET.	2.0	PRE-1920	160	ODOURS/FUMES	GAS	AIR	>10	GAS	WOOD	-	2
26	DET.	2.0	POST-1960	140	ODOURS/FUMES	GAS	AIR	>10	GAS	WOOD	WOOD	2
27	DET.	3.0	1921-45	150	NONE	GAS	AIR	>10	GAS	WOOD	-	0
28	DET.	2.0	POST-1960	300	POOR F.P STARTS	WOOD	AIR	>10	ELEC	WOOD	-	6
29	DET.	3.0	PRE-1920	150	NONE	GAS	AIR	>10	GAS	WOOD	-	2
30	DET.	2.0	PRE-1960	170	ODOURS/HEADACHES	GAS	AIR	0-5	GAS	WOOD	-	2
31	DET.	2.0	POST-1960	250	HEADACHES/RESPITORY	GAS	AIR	0-5	GAS	WOOD	WOOD	5
32	DET.	2.0	1946-60	120	NONE	GAS	AIR	5-10	GAS	WOOD	WOOD	3
33	DET.	3.0	POST-1960	180	NONE	GAS	AIR	0-5	GAS	WOOD	WOOD	1
34	DET.	1.5	1921-45	150	NONE	GAS	AIR	5-10	GAS	WOOD	-	1
35	DET.	1.0	POST-1960	105	NONE	GAS	AIR	0-5	GAS	WOOD	WOOD	3
36	DET.	1.0	1946-60	150	BACK PUFFING/DRAFT.	OIL	AIR	>10	GAS	WOOD	-	3
37	DET.	2.0	PRE-1920	150	NONE	GAS	AIR	>10	GAS	WOOD	-	1
38	DET.	2.0	1921-45	232	NONE	GAS	WATER	>10	GAS(2)	WOOD	-	4
39	DET.	1.0	1946-60	120	NONE	OIL	AIR	>10	OIL	WOOD	WOOD	3
40	DET.	2.0	POST-1960	200	NONE	GAS	AIR	5-10	GAS	GAS	WOOD	3

Notes:

(1) Dash line stands for no fire place.

TABLE 3 HOUSE DESCRIPTION - TORONTO

HOUSE ID	STYLE OF HOUSE *	NO. OF STOREYS **	DATE OF CONSTR-UCTION ***	FOOR AREA (m^2)	PREVIOUS VENTILATION PROBLEMS?	HEATING SYSTEM			DHW HEATER FUEL	FIRE PLACE		NO. OF FANS
						FUEL ****	DISTR. SYSTEM	AGE (YRS)		#1 FUEL	#2 FUEL	
41	DET.	SPLIT	POST-1960	126	SIGNS OF BACKDRAFT HEADACHES/RESPITORY	GAS	AIR	>10	GAS	WOOD	- (6)	1
42	DET.	2.5	POST-1960	200	NONE	GAS	AIR	>10	GAS	WOOD		3
43	DET.	2.0	POST-1960	251	NONE	GAS	AIR	0-5	GAS	WOOD	WOOD	3
44	DET.	1.0	POST-1960	115	NONE	GAS	AIR	>10	GAS	WOOD	-	4
45	DET.	2.0	(1)	250	NONE	GAS	AIR	0-5	GAS	WOOD	-	3
46	DET.	2.0	POST-1960	(2)	BACK PUFFING	GAS	AIR	>10	GAS	WOOD	WOOD	2
47	DET.	1.5	POST-1960	150	POOR F.P. STARTS	GAS	AIR	>10	GAS	WOOD	-	3
48	DET.	2.0	POST-1960	(3)	NONE	GAS	AIR	(5)	GAS	-	-	(7)
49	DET.	2.0	(4)	150	NONE	GAS	AIR	5-10	GAS	WOOD	-	2
50	DET.	2.0	POST-1960	175	NONE	GAS	AIR	5-10	GAS	-	-	2
51	DET.	2.0	POST-1960	240	NONE	GAS	AIR	0-5	GAS	-	-	2
52	DET.	2.0	POST-1960	150	NONE	GAS	AIR	0-5	GAS	-	-	1
53	DET.	2.0	POST-1920	200	BACK-PUFFING	GAS	AIR	>10	GAS	WOOD	WOOD	1
54	DET.	3.0	1946-60	(8)	ODOURS/BACKDRAFTING	GAS	WATER	0-5	GAS	WOOD	WOOD	(9)
55	DET.	2.0	POST-1920	320	NONE	GAS	AIR	0-5	GAS	WOOD	-	3
56	DET.	1.0	1946-60	120	NONE	GAS	AIR	0-5	GAS	-	-	1
57	DET.	2.0	1921-45	200	SIGNS OF BACKDRAFT	GAS	WATER	(10)	GAS	WOOD	-	2
58	DET.	2.5	POST-1960	200	HEADACHES/RESPIRATOR	GAS	WATER	0-5	GAS	WOOD	-	4
59	ROW	2.0	POST-1960	200	NONE	GAS	AIR	5-10	GAS	-	-	2
60	DET.	2.5	POST-1960	175	NONE	GAS	AIR	>10	GAS	WOOD	WOOD	4

Notes:

(1) Data not obtainable
(2) Data not obtainable
(3) Data not obtainable
(4) Data not obtainable
(5) Data not obtainable
(6) Dashed line stands for no fire place
(7) Data not obtainable
(8) Data not obtainable
(9) Data not obtainable
(10) Data not obtainable

TABLE 4 HOUSE DESCRIPTION - MANITOBA

HOUSE ID	STYLE OF HOUSE *	NO. OF STOREYS **	DATE OF CONSTR-UCTION ***	FOOR AREA (m^2)	PREVIOUS VENTILATION PROBLEMS?	HEATING SYSTEM			DHW HEATER FUEL	FIRE PLACE		NO. OF FANS
						FUEL ****	DISTR. SYSTEM	AGE (YRS)		#1 FUEL	#2 FUEL	
61	DET.	3.0	1921-45	220	NONE	GAS	AIR	0-5	GAS	WOOD	-	0
62	DET.	1.0	1946-60	75	NONE	GAS	WATER	5-10	(1)	WOOD	(2) -	0
63	DET.	2.0	POST-1960	200	SIGNS OF BACKDRAFT	GAS	AIR	>10	GAS	WOOD	-	3
64	DET.	2.0	POST-1960	160	NONE	GAS	AIR	0-5	GAS	WOOD	-	4
65	DUPL.	1.0	POST-1960	70	NONE	GAS	AIR	5-10	GAS	WOOD	-	3
66	DET.	2.0	POST-1960	150	NONE	GAS	AIR	5-10	GAS	WOOD	-	3
67	DET.	2.0	1946-60	170	NONE	GAS	AIR	>10	GAS	WOOD	-	2
68	DET.	2.0	1946-60	165	ODOURS/FUMES	GAS	WATER	>10	(3)	-	-	0
69	DET.	1.0	POST-1960	120	NONE	GAS	AIR	5-10	GAS	WOOD	-	3
70	DET.	1.0	POST-1960	130	NONE	GAS	AIR	0-5	(4)	WOOD	-	3
71	DET.	2.0	POST-1960	150	NONE	GAS	AIR	0-5	GAS	WOOD	-	4
72	DET.	1.0	POST-1960	90	NONE	GAS	AIR	5-10	GAS	-	-	3
73	DET.	1.5	1946-60	138	NONE	GAS	AIR	>10	GAS	-	-	3
74	DET.	1.0	POST-1960	90	NONE	GAS	AIR	>10	GAS	WOOD	-	2
75	DET.	2.0	POST-1960	200	NONE	GAS	AIR	0-5	GAS	WOOD	GAS	5
76	DET.	2.0	1946-60	140	NONE	GAS	AIR	>10	GAS	-	-	1
77	DET.	2.0	1946-60	137	SIGNS OF BACKDRAFT	GAS	AIR	>10	GAS	-	-	2
78	DET.	1.0	POST-1960	145	POOR F.P. START	GAS	AIR	0-5	GAS	WOOD	-	4
79	DET.	2.0	POST-1960	180	NONE	GAS	AIR	0-5	GAS	WOOD	-	5
80	DET.	1.0	1946-60	175	NONE	GAS	AIR	0-5	GAS	-	-	2

Notes:

(1) Data not obtainable
(2) Dashed line stands for no fire place
(3) Data not obtainable
(4) Data not obtainable

HOUSE DESCRIPTION - PRINCE EDWARD ISLAND

HOUSE ID	STYLE OF HOUSE *	NO. OF STOREYS **	DATE OF CONSTR-UCTION ***	FOOR AREA (m^2)	PREVIOUS VENTILATION PROBLEMS?	HEATING SYSTEM			DHW HEATER FUEL	FIRE PLACE		NO. OF FANS
						FUEL ****	DISTR. SYSTEM	AGE (YRS)		#1 FUEL	#2 FUEL	
81	DET.	2.0	POST-1960	225	NONE	OIL	WATER	(3)	OIL	WOOD	- (2)	2
82	DET.	1.5	POST-1960	165	NONE	OIL	AIR	(4)	PROP.	-	-	2
83	DET.	1.0	POST-1960	175	NONE	OIL	WATER	(5)	OIL	WOOD	-	4
84	DET.	1.0	POST-1960	150	BACK PUFFING POOR F.P. START	OIL	AIR	5-10	OIL	WOOD	WOOD	2
85	DET.	1.5	POST-1960	140	NONE	OIL	AIR	5-10	OIL	WOOD	-	2
86	DET.	1.0	POST-1960	185	NONE	OIL	AIR	(6)	OIL	WOOD	-	2
87	DET.	2.0	POST-1960	(1)	NONE	OIL	AIR	0-5	OIL	-	-	2
88	DET.	1.0	POST-1960	230	ODOURS FROM F.P. POOR F.P STARTS	OIL	AIR	0-5	OIL	WOOD	WOOD	1
89	DET.	1.5	1921-45	210	ODOURS FROM F.P. POOR F.P STARTS	OIL	AIR	(7)		WOOD	-	2
90	DET.	1.0	POST-1960	150	HISTORY OF BACKDRAFT STOVE REMOVED	OIL	AIR	(8)	OIL	-	-	2
91	DET.	1.0	POST-1960	210	NONE	OIL	AIR	(9)	ELEC.	-	-	2
92	DET.	1.0	POSST-196	205	BACK-PUFFING	OIL	WATER	(10)	OIL	WOOD	-	1
93	DET.	2.0	POST-1960	165	NONE	OIL	WATER	0-5	OIL	WOOD	-	3
94	DET.	1.0	POST-1960	200	ODOURS/FUMES	OIL	WATER	0-5	OIL	-	-	2
95	DET.	1.0	POST-1960	200	NONE	PROP.	AIR	0-5	PROP.	-	-	2
96	DET.	2.0	POST-1960	170	NONE	WOOD	WATER	0-5	WOOD	PROP.	-	0
97	DET.	2.0	POST-1960	175	NONE	OIL	AIR	(11)	OIL	-	-	2
98	DET.	1.5	PRE-1920	225	NONE	OIL	AIR	0-5	OIL	-	-	1
99	DET.	2.0	POST-1960	200	NONE	OIL	WATER	(12)	OIL	-	-	3
100	DET.	2.0	POST-1960	135	ODOURS / FLUMES	WOOD	AIR	0-5	PROP.	WOOD	WOOD	1

Notes:

(1) Data not obtainable
(2) Dashed line stands for no fire place
(3) Data not obtainable
(4) Data not obtainable
(5) Data not obtainable
(6) Data not obtainable

(7) Data not obtainable
(8) Dashed line stands for no fire place
(9) Data not obtainable
(10) Data not obtainable
(11) Data not obtainable
(12) Data not obtainable

TABLE 6 RESIDENTIAL COMBUSTION SAFTY CHECK - RESULTS SUMMARY - OTTAWA

HOUSE ID.	CHIMNEY INSPECTION PROBLEMS	FURNACE ROOM DEPRESSURIZATION (PASCALS)			HEAT EXCHANGER LEAKAGE	FURNACE SPILLAGE CHECK	FIREPLACE ROOM DEPRESSURIZATION IN PASCALS (MAXIMUM)	RELIEF OPENING REQ'D (cm^2	LABELS REQUIRED					TIME TO COMPLETE TEST (HOURS)
		FAILURE PRESSURE (SEE BELOW)	MECHANICAL EXHAUST PRESSURE (MAXIMUM)	MECH. PLUS FIREPLACE PRESSURE (MAXIMUM)		SECONDS OF SPILLAGE			FAN	COMB INLET	AIR INLET	FIRE (sml)	FIRE (lrg)	
1	A21,A7	6.0	NOT DONE	NO F.P.	NONE	>15.0	3.5	NONE	*	*		*		3.0
2	A2,A3	3.0	1.3	3.2	NONE	10.0	3.5	100				*		2.5
3	A17	5.0	5.0	7.5	NOT DONE	>15.0	3.5	NONE		*		*		2.0
4	A6,A12	(1)	0.5	NO F.P.	NONE	NONE	NO F.P.	NONE						1.5
5	NONE	3.1	3.0	3.6	NOT DONE	3.0	5.0	100		*				2.0
6	NOT DONE	4.5	4.0	5.5	NONE	PASS	4.5	100		*		*		1.7
7	A14	(1)	8.3	NO F.P.	NONE	7.0	NO F.P.	NONE	*	*				1.5
8	A18,C9	(1)	1.0	2.5	NONE	>15.0	2.0	NONE						1.5
9	NONE	(1)	1.2	2.7	NONE	2.0	2.7	NONE						2.0
10	A6	3.0	2.1	3.5	NOT DONE	10.0	4.6	270	*			*		2.5
11	A9,C9	(1)	2.0	3.5	NONE	>15.0	4.5	NONE						2.2
12	A13	4.0	5.7	6.9	NONE	2.0	6.7	400	*			*		2.5
13	NONE	(1)	2.0	4.0	NONE	5.0	3.0	NONE						2.0
14	A18	(1)	0.5	1.0	NOT DONE	10.0	1.0	NONE						1.5
15	C5,C9	(1)	1.0	1.5	NONE	5.0	2.5	NONE						2.0
16	NONE	(1)	1.5	3.0	NONE	10.0	1.5	NONE						1.2
17	NONE	3.0	3.0	5.2	NONE	NONE	5.0	120			*	*		2.0
18	A21,A18	(1)	1.5	3.0	NONE	>15.0	3.5	NONE		*		*		1.5
19	A14	(1)	0.9	2.0	NONE	5.0	1.5	NONE						1.5
20	A21,A18	(1)	2.9	NO F.P.	NONE	NONE	NO F.P.	NONE						1.0

(1) FURNACE ROOM DEPRESSURIZATION - FAILURE PRESSURE
A FAILURE PRESSURE IS RECORDED WHERE HOUSE DEPRESSURIZATION EXCEEDS MAXIMUM ALLOWABLE DEPRESSURIZATION LEVELS, EVEN AFTER OPENING AIR SUPPLY INLETS, CLOSING FIREPLACE DOORS, AND IMPLEMENTING ANY OTHER SAFTY MEASURES EXISTING IN THE HOUSE.

TABLE 7 RESIDENTIAL COMBUSTION SAFTY CHECK - RESULTS SUMMARY - BRITISH COLUMBIA

HOUSE ID.	CHIMNEY INSPECTION PROBLEMS	FURNACE ROOM DEPRESSURIZATION (PASCALS)			HEAT EXCHANGER LEAKAGE	FURNACE SPILLAGE CHECK	FIREPLACE ROOM DEPRESSURIZATION IN PASCALS (MAXIMUM)	RELIEF OPENING REQ'D (cm^2	LABELS REQUIRED					TIME TO COMPLETE TEST (HOURS)
		FAILURE PRESSURE (SEE BELOW)	MECHANICAL EXHAUST PRESSURE (MAXIMUM)	MECH. PLUS FIREPLACE PRESSURE (MAXIMUM)		SECONDS OF SPILLAGE			FAN	COMB INLET	AIR INLET	FIRE (sml)	FIRE (lrg)	
21	NONE	3.8	3.2	3.8	NONE	20	2.8	NONE		*				1.5
22	A18,AB5,AB8,B12,B16	(1)	1.1	3.5	NONE	10	2	NONE		*				2
23	A18,B11	3.5	2.1	4.1	NONE	NONE	2.9	NONE		*				2.2
24	C9,C6,	(1)	1	2	NONE	>15.0	2	NONE						1.5
25	NONE	(1)	0.5	1	NONE	NONE	0.5	NONE						1.5
26	A14,B11	(1)	1.0	2.2	NONE	NONE	1.6	NONE						1
27	NONE	(1)	1.2	2.8	NONE	NONE	0.5	NONE						2
28	NONE	(1)	1.2	2.8	NONE	NONE	2.8	NONE						1
29	NONE	(1)	1.1	2.2	NONE	NONE	1.8	NONE						1.7
30	A14,AIR EXCHANG.21	5.2	8.5	10.5	NONE	>15	7.5	SHUT DOORS	*	*		*		4
31	AB12	8.4	9.2	15	NONE	>15	NOT DONE	NONE	*	*	*	*	*	3
32	C6,A14	3.5	3.5	6	NONE	>15	7	1200	*			*	*	2.5
33	NONE	4.2	2.1	5.1	NONE	NOT DONE	NOT DONE	NONE		*		*	*	3
34	A7,C9	(1)	0.1	0.1	NONE	2	0.1	NONE						1
35	A17,A18	(1)	1.2	2.2	NONE	NONE	4	NONE						1.5
36	A1	6	3.9	6	NONE	NONE	4.7	NONE				*		1.5
37	A8,A14,A16,A17,A19	(1)	0.2	1	SLIGHT	NONE	0.2	NONE						2
38	NONE	(1)	1.8	2.4	NONE	NONE	2.3	NONE						2
39	NONE	(1)	2.5	4	NONE	NONE	3	NONE						1.5
40	NONE	3	3	NO F.P.	NONE	>15.0	NO F.P.	NONE	*					

(1) FURNACE ROOM DEPRESSURIZATION - FAILURE PRESSURE
A FAILURE PRESSURE IS RECORDED WHERE HOUSE DEPRESSURIZATION EXCEEDS MAXIMUM ALLOWABLE DEPRESSURIZATION LEVELS, EVEN AFTER OPENING AIR SUPPLY INLETS, CLOSING FIREPLACE DOORS, AND IMPLEMENTING ANY OTHER SAFTY MEASURES EXISTING IN THE HOUSE.

TABLE 8 RESIDENTIAL COMBUSTION SAFTY CHECK - RESULTS SUMMARY - TORONTO

HOUSE ID.	CHIMNEY INSPECTION PROBLEMS	FURNACE ROOM DEPRESSURIZATION (PASCALS)			HEAT EXCHANGER LEAKAGE	FURNACE SPILLAGE CHECK	FIREPLACE ROOM DEPRESSURIZATION IN PASCALS (MAXIMUM)	RELIEF OPENING REQ'D (cm^2)	LABELS REQUIRED					TIME TO COMPLETE TEST (HOURS)
		FAILURE PRESSURE (SEE BELOW)	MECHANICAL EXHAUST PRESSURE (MAXIMUM)	MECH. PLUS FIREPLACE PRESSURE (MAXIMUM)		SECONDS OF SPILLAGE			FAN	COMB INLET	AIR INLET	FIRE (sml)	FIRE (lrg)	
41	C2	(1)	1.5	4	NONE	5	2	NONE						1.7
42	NONE	(1)	2	3	NONE	7	2	NONE						1.0
43	NONE	(1)	1	1	NONE	3	1	NONE						1.5
44	NONE	(1)	0.5	1	NONE	NONE	1	NONE						2.0
45	NONE	(1)	1	1	NONE	5	1	NONE						1.0
46	NONE	3.5	3	3.5	NONE	>15.0	3.5	NONE	*					2.0
47	NONE	(1)	1.5	4	NONE	NONE	2.5	NONE						1.5
48	NONE	(1)	2	3.5	NONE	10	3.5	NONE				*		1.5
49	A2,A5,B14	(1)	2	2	NONE	NONE	2.5	NONE						1.5
50	NONE	(1)	0	1	NONE	3	1	NONE						1.0
51	NONE	(1)	1	1.5	NONE	NONE	2	NONE						1.0
52	NONE	(1)	1.5	1.5	NONE	5	1	NONE						1.0
53	A19	3	2	3	NONE	5	3	NONE				*		2.0
54	NONE	(1)	0	0	NONE	NONE	0	NONE						1.5
55	NONE	(1)	1.5	3	NOT DONE	10	1	NONE						1.0
56	A9	(1)	1.5	NO F.P.	NONE	NONE	NO F.P.	NONE						1.0
57	NONE	(1)	1.5	NOT DONE	NOT DONE	NOT DONE	1	NONE						1.0
58	NONE	4.5	2.5	4.5	NONE	NOT DONE	2	NONE						1.0
59	NONE	(1)	1	NO F.P.	NONE	NONE	NO F.P.	NONE						1.0
60	NONE	(1)	1.5	2	NONE	5	1.5	NONE						1.5

(1) FURNACE ROOM DEPRESSURIZATION - FAILURE PRESSURE
A FAILURE PRESSURE IS RECORDED WHERE HOUSE DEPRESSURIZATION EXCEEDS MAXIMUM ALLOWABLE DEPRESSURIZATION LEVELS, EVEN AFTER OPENING AIR SUPPLY INLETS, CLOSING FIREPLACE DOORS, AND IMPLEMENTING ANY OTHER SAFTY MEASURES EXISTING IN THE HOUSE.

TABLE 9 RESIDENTIAL COMBUSTION SAFTY CHECK - RESULTS SUMMARY - MANITOBA

HOUSE ID.	CHIMNEY INSPECTION PROBLEMS	FURNACE ROOM DEPRESSURIZATION (PASCALS)			HEAT EXCHANGER LEAKAGE	FURNACE SPILLAGE CHECK SECONDS OF SPILLAGE	FIREPLACE ROOM DEPRESSURIZATION IN PASCALS (MAXIMUM)	RELIEF OPENING REQ'D (cm^2)	LABELS REQUIRED					TIME TO COMPLETE TEST (HOURS)
		FAILURE PRESSURE (SEE BELOW)	MECHANICAL EXHAUST PRESSURE (MAXIMUM)	MECH. PLUS FIREPLACE PRESSURE (MAXIMUM)					FAN	COMB INLET	AIR INLET	FIRE (sml)	FIRE (lrg)	
61	NONE	(1)	1.4	5	NONE	NONE	1.5	NONE						2.5
62	NONE	(1)	0	2.2	NONE	NONE	0.6	NONE						2.2
63	NONE	12	12.6	15.6	NONE	5	NOT DONE	NONE	*	*				2
64	NONE	9.8	4.2	9.8	NONE	20	8	114				*		2
65	NONE	9.4	9.4	12.2	NONE	NONE	2.4	NONE	*	*		*		1.5
66	NONE	9.8	5	9.8	NONE	20	5.8	98.8			*			2
67	A8	(1)	3.6	4.4	NONE	NONE	1.4	NONE						2
68	A16	(1)	0	NO F.P.	NONE	>15.0	NO F.P.	NONE						1.2
69	NONE	(1)	2	2.8	NONE	12	0.2	NONE						1.7
70	NONE	5.3	6	8	NOT DONE	NOT DONE	0.6	NONE	*	*		*		1
71	NONE	5.8	5.2	8	NONE	17	0.8	NONE		*		*		1.2
72	NONE	9.4	9.4	NO F.P.	NONE	14	NO F.P.	NONE	*					1.2
73	NONE	(1)	3.4	NO F.P.	NONE	8	NO F.P.	NONE						1.5
74	NONE	(1)	1.4	3	NONE	NONE	0.5	NONE						1.2
75	NONE	6.4	4.2	6.4	NONE	2	2.4	NONE				*	*	2.2
76	NONE	(1)	1.8	NO F.P.	NONE	13	NO F.P.	NONE						1.2
77	NONE	(1)	4.6	NO F.P.	NONE	NONE	NO F.P.	NONE						1.3
78	NONE	10.6	12.1	15.1	NONE	5	0	NONE						1.3
79	NONE	15	16.8	22.2	NONE	NONE	0	NONE						1.0
80	NONE	7.6	7.6	NO F.P.	NONE	3	NO F.P.	NONE						1.0

(1) FURNACE ROOM DEPRESSURIZATION - FAILURE PRESSURE
A FAILURE PRESSURE IS RECORDED WHERE HOUSE DEPRESSURIZATION EXCEEDS MAXIMUM ALLOWABLE DEPRESSURIZATION LEVELS, EVEN AFTER OPENING AIR SUPPLY INLETS, CLOSING FIREPLACE DOORS, AND IMPLEMENTING ANY OTHER SAFTY MEASURES EXISTING IN THE HOUSE.

TABLE 10 RESIDENTIAL COMBUSTION SAFTY CHECK - RESULTS SUMMARY - PRINCE EDWARD ISLAND

HOUSE ID.	CHIMNEY INSPECTION PROBLEMS	FURNACE ROOM DEPRESSURIZATION (PASCALS)			HEAT EXCHANGER LEAKAGE	FURNACE SPILLAGE CHECK	FIREPLACE ROOM DEPRESSURIZATION IN PASCALS (MAXIMUM)	RELIEF OPENING REQ'D (cm^2)	LABELS REQUIRED					TIME TO COMPLETE TEST (HOURS)
		FAILURE PRESSURE (SEE BELOW)	MECHANICAL EXHAUST PRESSURE (MAXIMUM)	MECH. PLUS FIREPLACE PRESSURE (MAXIMUM)		SECONDS OF SPILLAGE			FAN	COMB INLET	AIR INLET	FIRE (sml)	FIRE (lrg)	
81	A12,A16,A1	(1)	3.0	3.0	NONE	NONE	5.0	NONE				*		2.0
82	A11,A13,A1	4.8	4.8	NO F.P.	NONE	3.0	NO F.P.	NONE	*					1.5
83	NONE	4.5	4.5	5.5	NONE	NONE	4.2	228.6	*			*		2.0
84	A13,C15	9.2	11.2	17.7	NONE	>60.0	3.5	19.5	*	*	*	*	*	2.0
85	C6.C9	(1)	0.2	NO F.P.	NONE	NONE	NO F.P.	NONE						2.0
86	A2,A5,A6 C9	4.5	4.5	6.0	NONE	NONE	5.0	175.0	*			*		2.0
87	NONE	6.0	6.0	NO F.P.	NOT DONE	1.5	NO F.P.	NONE	*					2.0
88	C9,C2	(1)	0.2	1.5	NONE	NONE	2.4	NONE						3.0
89	A12,A5,C2 C6,C9	(1)	0.0	0.4	NONE	NONE	0.7	NONE						1.5
90	A2	(1)	3.0	NO F.P.	NONE	NONE	NO F.P.	NONE						1.2
91	NONE	(1)	3.5	NO F.P.	NOT DONE	NONE	NO F.P.	NONE						1.1
92	NONE	(1)	0.8	3.2	NONE	NONE	3.7	87.5				*		1.5
93	NONE	(1)	1.5	2.0	NOT DONE	NONE	2.2	NONE						1.2
94	NONE	4.2	5.0	5.0	NONE	NONE	0.0	NONE	*	*				1.0
95	NONE	4.0	7.5	NO F.P.	N/A	NONE	NO F.P.	NONE	*	*				1.3
96	NONE	(1)	0.0	2.5	N/A	NONE	0.5	NONE						1.0
97	NONE	(1)	3.8	NO F.P.	NONE	NONE	NO F.P.	NONE						1.3
98	C5	(1)	0.0	1.6	NONE	NONE	2.2	NONE						1.3
99	A11,A13,A1	(1)	0.0	NO F.P.	NONE	NONE	NO F.P.	NONE						0.6
100	NONE	(1)	0.0	NOT DONE	NOT DONE	NOT DONE	2.8	NONE						0.6

(1) FURNACE ROOM DEPRESSURIZATION - FAILURE PRESSURE
A FAILURE PRESSURE IS RECORDED WHERE HOUSE DEPRESSURIZATION EXCEEDS MAXIMUM ALLOWABLE DEPRESSURIZATION LEVELS, EVEN AFTER OPENING AIR SUPPLY INLETS, CLOSING FIREPLACE DOORS, AND IMPLEMENTING ANY OTHER SAFTY MEASURES EXISTING IN THE HOUSE.

FIGURE 2 MAD LIMITS USED BY FIELD EVALUATORS

MAXIMUM ALLOWABLE DEPRESSURIZATION (MAD Limits)

APPLIANCE	IGNITION	DRAFT	TOTAL CHIMNEY HEIGHT (m)	LIMIT (Pa)
Gas-fired DHW	pilot	natural	NA	3.0
	electronic	natural	NA	2.0
	electronic	induced	NA	5.0
Oil-fired DHW	electronic	natural	NA	4.0
Gas furnace/boiler	pilot	natural	2 - 4	4.0
	pilot	natural	4 - 8	5.0
	electronic	natural	2 - 4	3.0
	electronic	natural	4 - 8	4.0
	electronic	induced	NA	6.0
	pilot	forced	NA	6.0
Oil furnace/boiler	electronic	natural	NA	4.0
	pilot	forced	NA	4.0
Fireplaces	NA	natural	NA	3.0

FIGURE 3 CAUATIONARY LABELS USED BY FIELD EVALUATORS

CAUTION: AVOID CHIMNEY FAILURE
ENSURE THAT BLOWER COMPARTMENT IS LEFT TIGHTLY CLOSED AT ALL TIMES!
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
Do not operate this fireplace at times when other fireplaces are operating.
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
Provide additional air supply from outdoors before operating this exhaust fan.
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
ENSURE THAT BLOWER COMPARTMENT IS LEFT TIGHTLY CLOSED AT ALL TIMES!
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
Provide additional air supply from outdoors while operating this fireplace.
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
DO NOT BLOCK OR RESTRICT THIS OPENING!
Date:____________ Initials:_____

CAUTION: AVOID CHIMNEY FAILURE
Keep fireplace doors shut and air supply open as the fire burns down.
Date:____________ Initials:_____

Outside air supply is essential for the safe operation of combustion appliances in this house.

Figure 4

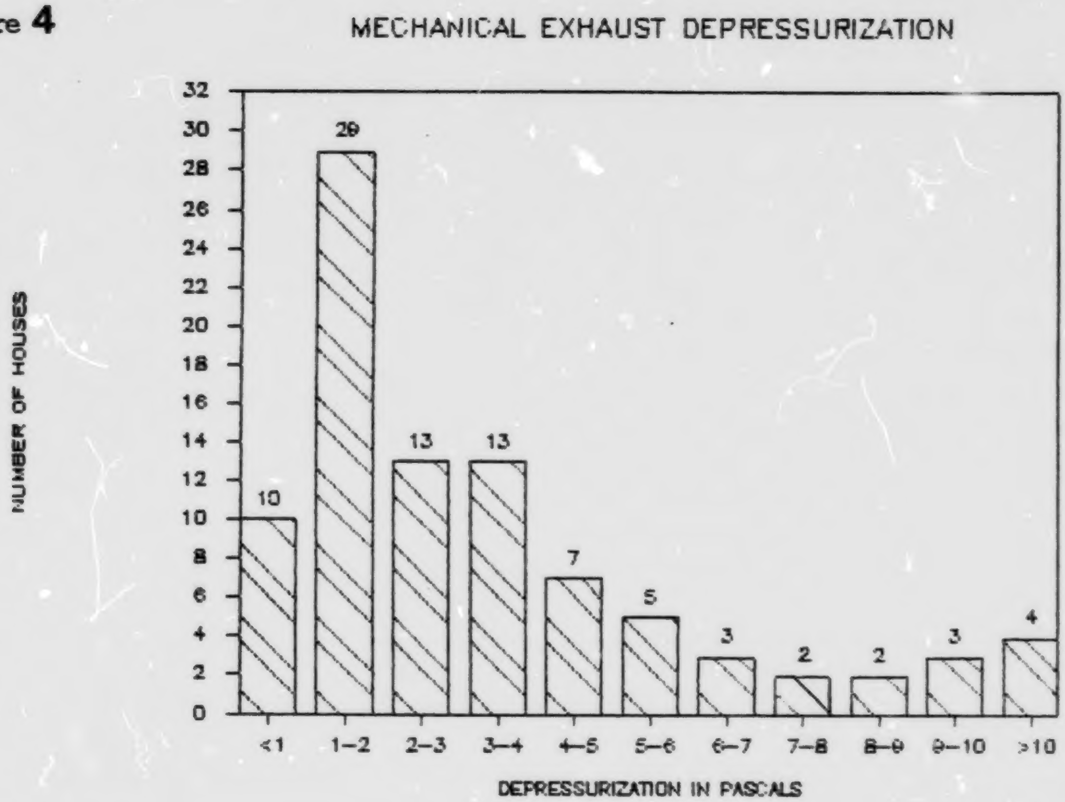
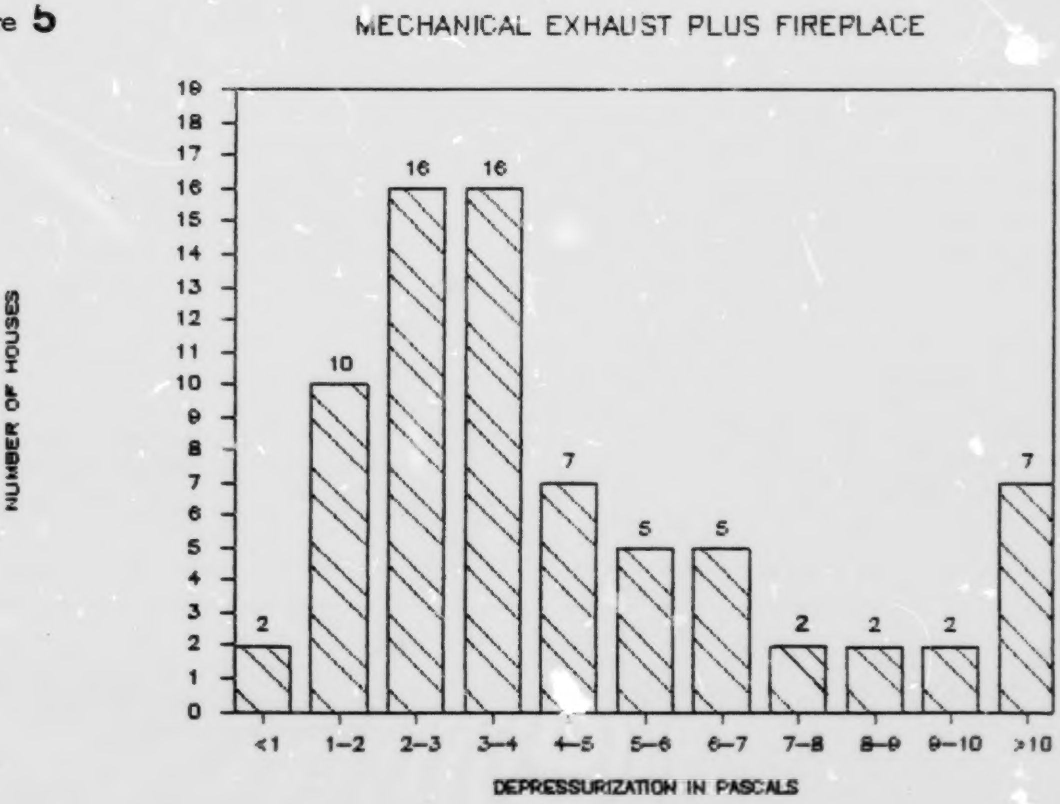


Figure 5



RESIDENTIAL COMBUSTION SAFETY CHECKLISTS

APPENDIX 1

THE COMBUSTION VENTING SAFETY CHECK

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Prepared for:

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

by:

Sheltair Scientific Ltd.

March, 1985

APPENDIX I

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INTRODUCTION

The Combustion Safety Check or 'Safety Check,' is a test designed for use on houses with oil or gas fired heating systems. Its purpose is to determine if the potential exists for pollution of indoor air, by heating appliances or fireplaces. The on-site procedures have been summarized, for convenience, on the Safety Check form (located at the end of this section). However, the detailed procedures presented in this Manual should be followed until the user becomes familiar with all components of the Safety Check.

The Safety Check can be used to identify most types of combustion ventilation hazards in housing. These include:

- backdrafting of chimneys on furnaces, water heaters and fireplaces -- caused by imbalanced ventilation systems;
- leaky heat exchangers on furnaces;
- spillage from blocked, broken, or damaged chimneys;
- spillage, or fire hazards - from poor chimney design;
- spillage or carbon monoxide production - due to poor maintenance of chimneys and appliances;
- spillage, or other hazards - due to over-firing of a gas appliance.

The Safety Check does not provide a 100% guarantee of safe operation. No combustion appliance is ever 100 percent safe. However, the use of Safety Check has been shown to accurately identify most common problems with combustion venting in houses.

The Safety Check is particularly useful as a diagnostic procedure, for use in situations where occupants have already experienced difficulties. Another especially useful application is in houses where renovation or retrofit activities might have altered the existing air supply or exhaust capacity.

When the Safety Check procedure is conducted on a typical home, an experienced technician should expect to spend 1 to 1-1/2 hours on-site. Total time will vary with such factors as number of appliances and number of failures experienced in a particular house. Another very important factor is whether the occupant of the house is a help, or a hindrance.

1. An Explanation of the Safety Check Form

The Safety Check form condenses all essential information and data on a single page. This form is initially divided into five PARTS, each representing a different component of the Safety Check. This approach allows the tester to easily condense the Safety Check procedures, if necessary. For example, PART 3 is a test for leaking heat exchangers and can easily be skipped if a home were heated by a boiler.

All boxes on the form are to be either checked (✓) or exed (X) during the process of completing a Safety Check.

A check indicates that the particular item has been completed (or applies to the house under test).

An X indicates that, for some reason, this step of the Safety Check has been omitted.

By reviewing the Xs and checks (✓'s) on a form, it is possible to determine the types of appliances and systems in a particular house.

A Results Summary is provided for each part of the Safety Check. An open line, opposite a question item in this section, indicates that the user is expected to insert data or comments, (rather than a check or an X).

Below the 'Results Summary' is the condensed version of the procedures to be followed for each part of the Safety Check. Note that every step of the procedure has been itemized on the form, and is accompanied by a check-off box.

Checking or "X"ing each box is an important part of conducting a field Safety Check. The check-offs ensure that no stage of the procedure is missed and provide a guarantee of safe and correct procedures. This is especially important in regards to health and safety issues, such as unplugging chimneys, untaping inlets, and resetting thermostats or appliance controls.

Part 1 of the Safety Check is titled **Chimney Inspection.** This inspection involves a thorough examination of all the chimneys of a house, first from outside and then from inside of the home. The intention is to visibly identify signs of appliance malfunction or deterioration in the chimney, and to make recommendations for preventative maintenance.

A second objective of the Chimney Inspection is to ensure that the appliances are designed and operating in a conventional fashion, and are thus suitable for evaluation by the Safety Check. The standards and techniques described in this measure pertain only to conventional appliances, in good repair, that meet existing codes.

Part 2 of the Safety Check is titled **Furnace Room Vent/Pressure Test.** Part 2 will determine whether, under the worst case conditions, the exhaust systems of the house are capable of creating hazardous backdrafting, in either the furnace or DHW chimneys. In this test, there is no actual measurement of chimney draft, since this will vary considerably with winds and temperatures. Instead, an assumption is made about the minimum possible total chimney draft. A pressure gauge is then used to determine if the house depressurization is likely to exceed the assumed chimney draft. In this way, without requiring any special test conditions, such as calm winds or warm temperatures, the gauge provides an accurate indication of the potential backdraft hazards in the house, as well as the safety margin.

Part 3 of the Safety Check is titled **Heat Exchanger Leakage.** The intention is to determine if a furnace might be experiencing leakage around or across the walls of its heat exchanger. The techniques differ slightly between gas and oil fired furnaces.

Part 4 of the Safety Check is titled **Furnace Room Spillage Check.** The intention of this test is to determine whether the existing chimney is capable of handling the maximum flow of combustion gases without experiencing excessive spillage. Since some small amount of spillage is sometimes an inevitable occurrence, with naturally aspirated appliances during the start-up period, it is necessary to test for, and to time the spillage. The spillage check is conducted under worst case conditions, in a similar fashion to Part 2 of the Safety Check. A spillage period of longer than fifteen (15) seconds is normally considered unacceptable.

Part 4 subjects gas fired appliances to two additional tests. The first involves clocking the gas meter, to allow for calculation of the firing rate. The second is a test of the carbon monoxide concentration in the flue gas. For safe operation, it is assumed that a gas appliance should not be more than 15% over-fired, and should not have more than 50ppm CO in its combustion gases before dilution.

Part 5 of the Safety Check is the Fireplace Vent/Pressure Test. It is similar to Part 2 of the Check, but measures the effect of house pressures on fireplace draft. A maximum allowable depressurization limit has been set for fireplaces in houses, and the pressure gauge is once again used to determine if house exhaust systems (now including furnace and DHW) are capable of exceeding this limit. The limit is expressed in terms of Pascals of pressure difference between outdoors and the fireplace room.

A Description of the Safety Check Form: Side 2

The reverse side of the form contains a number of questions regarding remedial actions taken on the house, and follow-up action required. When used properly, the Safety Check form represents a complete commentary and documentation of the steps taken during the Check, results of the tests, and follow-up action required.

The reverse side of the Safety Check form also contains a number of reference tables and equations. Table 1 lists suggested tools for use in each part of the Safety Check. Before leaving to conduct a Safety Check on a house, the user can review this tool list and check off all appropriate items.

Below the suggested tool list is Table 2, titled **Maximum Allowable Depressurization.** This table contains safety limits for various appliances. The limits are expressed in terms of Pascals of pressure difference, between the room in which the appliance is located, and the out-of-doors. These limits vary depending on the type of appliance, the type of ignition, the method of draft, and the chimney height. For example, a gas-fired furnace, with a conventional pilot light ignition, and a naturally aspirated 4 meter chimney, has a limit of 4 Pascals. A house, with such a furnace will fail the Safety Check procedure if the total exhaust systems in the house are found capable of depressurizing the furnace room by 4 Pascals (or more), relative to outdoors. Table 2 is essential for determining whether a particular house has failed Parts 2 or 5 of the Checklist procedure.

When failures occur, because the limits on the table are exceeded, the technician may choose to apply appropriate cautionary labels. For some appliances, there may be more than one limit. Exceeding the first limit justifies application of a cautionary label; exceeding the second limit means that the situation is hazardous enough to warrant special Remedial Measures.

COMBUSTION VENTILATION SAFETY CHECK

Results Summary

Address Street Municipality Arr. time__:__
Date________ Compl.time__:__

1. CHIMNEY INSPECTION

ALL OK__ NOT DONE__ MAINTENANCE RECOMMENDED__
MAINTENANCE REQ'D__
PROBLEMS (specify A1 A2,etc) ______________________________

INSPECTION LIST: (FURNACE=A DHW=B FIREPLACE=C)

1 cap needs repair
2 clearance insufficient
3 supports inadequate
4 brickwork needs repair
5 top sooted or stained
6 lining needs repair
7 lining missing (gas)
8 creosote excessive
9 flue wrong size
10 flue connector loose
11 flue connector corroded
12 damper imbalanced
13 hood stained or rusted
14 connector design problem
15 fuel odors present
16 blower compartment loose
17 filter plugged
18 burner dirty or sooted
19 air supply plugged
20 inlet poorly located

2. FURNACE ROOM VENT/PRESSURE TEST

ALL OK __ NOT DONE __ N/A __ INITIAL FAILURE __
Initial Pressure: FANS 2way___ exhaust___ blower___
FIRE sm___ lg___
Reduced Pressure: FANS 2way___ exhaust___ blower___
FIRE sm___ lg___
Relief Measures Taken: ______________________________
CLOSE: ext doors __ windows __ int doors __
TURN OFF: furnace pilot __ DHW __ stove __
SET UP: tubing __ gauge __
CLOSE INLETS:furnace rm__ house__ firepl__
CLOSE CHIMNEYS: furn__ DHW__ fpl dampers__

FANS OFF & COVERS REMOVED: __

ZERO GAUGE: __

OPERATE FANS: range __ stovetop __ bath1 __ bath2__
bath3__ dryer__ vacuum __ special __

RECORD PRESSURES: fans on __ blower on __
(Fails? inlets open__ labels applied__)

PREPARE SM FPL: window open__ chimney open__ air supply
open__ firepl doors open__ burner high__
check draft __ window closed__

CHECK FPL SPILLAGE: __(Fails? close firepl OR open window__
apply label__)

RECORD PRESSURE: __ (Fails? close fireplace doors __ apply
labels__)

3. HEAT EXCHANGER LEAKAGE TEST

ALL OK __ NOT DONE __ SLIGHT FAILURE __ MAJOR FAILURE __

Describe leakage:____

GAS

PREPARATION: pilot light off __ flue still plugged __

PREPARE EQUIPMENT: smoke ready __ light on __

SMOKE CHECK PORTS WITH BLOWER OFF: bottom __ top __

TEST LEAKAGE: blower on __ repeat smoke checks __

RESET FURNACE: blower off__ chimney open__ pilot lit__

OIL

PREPARATION: ensure burner off __ flue still plugged __
register open __ port open __
smoke candle & lighter ready __

PREPARE EQUIPMENT: smoke ready __ port open __

SMOKE CHECK PORTS WITH BLOWER OFF: bottom __ top __

TEST LEAKAGE: blower on __ repeat smoke check __

RESET FURNACE: blower off __ chimney open __ port closed __

RECORD PRESSURE: __ (Fails? determine best remedial measure:

1. open any inlets to furnace rm or house __ passes __
2. close any fpl doors & relocate tubing __ passes __
3. shut off any other fpl __ passes __

COMPLETION

ENSURE FLUES OPEN: furnace __ DHW __ stove __

OPEN INLETS: furnace rm__ house__ crawl spc__

RESET: furnace pilot__ thermostat__ DHW valve__

CHECK FURNACE OPERATION: full cycle__ flame color__ fans__

fireplace dampers__ __

A RECORD OF REMEDIAL ACTIONS TAKEN

LABELS APPLIED

Exhaust Fan ____ Combustion air ____ Fresh air____ Blower____

Sml Fireplace____ Lge Fireplace____ Furnace ____ DHW ____

ADVICE TO OCCUPANT

Verbal Explanation __

Literature ______________________________

Referral to ______________________________

INLET INSTALLED

Size ______________________________

Location ______________________________

OTHER WORK ______________________________

FOLLOW-UP REQUIRED

None__ Urgent__ Today__ Routine__ Optional__

(Details:) ______________________________

TABLE 1: SUGGESTED TOOL LIST

1 INSPECTION:

__ adj. mirror
__ flash
__ ratchet
__ multi-screwdriver
__ binoculars
__ tape measure
__ fan labels
__ inlet labels
__ fireplace labels

3 HEAT EXCHANGER:

__ smoke extension kit
__ smoke pencil

4 CHIMNEY SPILLAGE:

__ propane stove
__ butane lighter
__ timepiece
__ hand pump
__ CO tubes
__ static pressure tip

2&5 FURNACE OR FIREPLACE ROOM TESTING:

__ manometer
__ tubing & connectors
__ 3" masking tape
__ balloons & tube

FIREPLACES:

__ propane stovetop
__ butane lighter
__ propane canister

TABLE 2: MAXIMUM ALLOWABLE DEPRESSURIZATION (MAD Limits)

APPLIANCE	IGNITION	DRAFT	TOTAL CHIMNEY HEIGHT (m)	LIMIT (Pa)
Gas-fired DHW	pilot	natural	NA	3.0
	electronic	natural	NA	2.0
	electronic	induced	NA	5.0
Oil-fired DHW	electronic	natural	NA	4.0
Gas furnace/ boiler	pilot	natural	2 - 4	4.0
	pilot	natural	4 - 8	5.0
	electronic	natural	2 - 4	3.0
	electronic	natural	4 - 8	4.0
	electronic	induced	NA	6.0
	pilot	forced	NA	6.0
Oil furnace/ boiler	electronic	natural	NA	4.0
	pilot	forced	NA	4.0
Fireplaces	NA	natural	NA	3.0

FIRING RATE CALCULATIONS

$$\text{Thousand BTU/hr Input} = \frac{\text{seconds req'd for dial to record 1 ft3}}{3852}$$

$$\text{Percentage Overfiring} = \frac{\text{actual rate - nominal rate} \quad * \ 100}{\text{nominal rate}}$$

2. Description of Tools and Equipment

Adjustable serviceman's mirror -- An adjustable mirror provides a means of looking up the flue of a chimney. The mirror is typically extended to full length and the end of the mirror adjusted to an appropriate angle. The angle is usually only slightly tilted upwards from the extension handle itself. Initially, these mirrors are coated on both sides with a protective sticky paper. It is recommended that you remove this protective covering on one side only, allowing the other side to remain covered until such time as it is required.

The use of the mirror provides an excellent way of identifying partial or complete blockage of a flue. It is difficult, however, to obtain a good image of the condition of the inside lining of a chimney using a mirror. Experimentation will show that, when the mirror is combined with a flashlight, it is usually possible to get good visual images of the lining immediately adjacent to and above the location of the mirror, but that, at the upper reaches of the chimney lining, where problems are most likely to be occurring, it is virtually impossible to distinguish any relevant features.

Flashlight -- A flashlight is a useful item, when working in a dark furnace room, or when looking into flue connectors and chimneys. (An alternative is to use the pen light attached to the smoke pencil extension.)

Ratchet -- A small ratchet is useful for removing and attaching sheet metal screws on the flue connector.

Multi-tipped screwdriver -- A screwdriver is a multi-purpose tool that is useful for such tasks as adjusting gauges and tightening loose furnace components.

Telescope -- A hand-sized telescope (or binoculars) is sometimes used for the examination of chimney conditions outside a house.

Tubing -- 7.4mm (3/16") ID plastic tubing is necessary for connecting a pressure gauge to various parts of the house and for tapping outdoor pressures. Under calm or moderate wind conditions, most of this tubing will not be required. One 15m length of tubing (marked with red tape) is used inside the house and will be attached to the left port of the manometer and then extended, as directed, to either the furnace room or the fireplace room. Another 15m section of tubing (blue tape) is to be connected to the right side of the manometer gauge and extended through an opening in the envelope of the house to a sheltered location away from the house. As long as winds are not gusty, and do not exceed 15kph, it will be possible to use only these two sections of tubing, while completing the Safety Check. The exterior pressure tap is to be fitted with a windscreen and pressure-dampening tip.

Additional tubing connectors and sections of tubing, must be used during windy conditions. The additional tubing is stretched around to all four faces of the house, in a similar fashion to the CGSB Fan Depressurization Test procedure (CAN2-149-GP). An octopus connector replaces the windscreen and dampening tip at the end of the exterior (blue) tap and allows you to branch off to all four sides of the house. Quick-connect couplers make this an easy process, although it is extremely important not to allow tubing to become twisted, entangled, or mixed up with other sections. Yellow tubing is for either side, and green tubing is for the opposite face.

Manometer -- An inclined manometer is required for measuring indoor/outdoor pressure differences. The scale on this gauge must read only in Pascals (rather than inches H2O) for this Safety Check. The gauge must be specified accurate to 0.6 Pa., although, with careful reading, it is easy to read non-electronic manometers accurately to 0.2 Pa. Detailed operating instructions, and manufacturer information on this gauge, will be provided in the Manufacturer's Catalogue and are essential reading. Particular attention should be given to sections on how to read the scale, (i.e.the techniques for lining up the meniscus with its reflection on the scale, to ensure a direct reading). When first setting up the gauge, be sure to eliminate bubbles in the fluid (by blowing on the left port until the bubbles join the vertical cavity), and to align the gauge so that it is level and stable. An appropriate manometer is a Droyer Model 115.

120mm (3") Masking Tape -- A roll of masking tape will be useful for taping up air inlets, for taping up barometric dampers on oil flues, and for attaching pressure tubing to the exterior faces of houses.

Balloons and Tube -- The balloon flue sealer is a quick and easy way of temporarily plugging flues. Two flue sealers are required, since in most cases there will be both a furnace and a hot-water heater flue that require plugging. With practice, it becomes easy to determine just how much air is required to fill a balloon to the diameter of the flue pipe. It is important, when feeding these balloons into the flue pipe, to avoid catching the surface of the balloon on the inside points of sheet metal screws. For added protection, the balloon is usually first covered in heavy plastic bagging. Condoms (non-lubricated) have been found to work somewhat better than balloons, since they expand more readily and to a larger diameter.

Propane Stovetop -- This stovetop simply screws onto the top of a propane canister. Its purpose is to simulate fireplace operation, in a clean and convenient fashion. A 150mm diameter burner will produce adequate heat for the Safety Check purposes, but only when operating at completely full throttle. This stove should be designed to burn relatively cleanly, and to operate at full throttle, without damage, for extended periods of time. An appropriate model is a Coleman 5422A701.

Lighter -- A hand-held butane lighter is used for lighting propane stoves. It can also be used for checking chimney draft and chimney spillage, in place of a smoke pencil. The lighter is not as good for checking drafts as a conventional smoke pencil; however, with practice, it will serve the purpose in a much more convenient and less expensive fashion. Note that the new electronically ignited butane lighters have an easily adjusted flame control switch on the front, and are much more convenient to relight and hold.

Propane Canister -- A propane canister is required for use with the propane stovetop.

Timepiece -- A watch, stopwatch, or other timepiece, is required for timing the length of any spillage, and for clocking gas meters.

Tape Measure -- A tape measure is required in cases where a failure results during PART 2 or 5 of the Safety Test. The tape measure is used for measuring the size of relief openings - i.e. window or door openings required to lower pressures, in furnace or fireplace rooms, to a point below the limit specified in the Maximum Allowable Depressurization Table. The tape measure should be metric.

Labels -- Foil-faced, sticky-backed labels are required for failure houses. These labels are to be attached to appliances, inlets, fireplaces, or other locations where a failure warrants cautionary advice to the occupants.

Smoke Pencils and Squeeze Bulb -- Smoke pencils are glass tubes containing a carrier material impregnated with a sulfur or hydrogen compound. When household air is drawn through the tube, the humidity reacts with the chemicals to create a cool, white, dense(?) acidic smoke. The squeeze bulb is used to squirt air through the tube. The smoke is needed for the heat exchanger leakage test on gas furnaces, and for general identification of spillage problems.

Smoke Pencil Extension Kit -- A 100mm piece of flexible plastic tubing, attached to a 500mm length of copper tubing is required for heat exchanger testing. The inside diameter of the tubing should be approximately 6mm. A pen light is strapped to the middle section of the copper tubing. The flexible end of the extension tubing is fitted over the end of a smoke pencil. Squeezing the smoke pencil bulb forces smoke through the copper tubing and permits a check of air currents in each port of a gas furnace, or through the inspection port of an oil furnace. The pen light illuminates the smoke as it trails out the end of the copper tubing.

Hand Pump and CO Tubes -- A hand pump and colorimetric detector tubes are used for sampling combustion gases, for concentration of carbon monoxide (CO). The two most common commercial systems are Draeger (bellows pump and Tube CH25601) and Gastec (pump 800 and Tube 1LL). The pump is used to draw a standard volume of combustion gases through a glass tube, containing a chemical that reacts with CO. Colour staining on the tube gives a direct reading of CO, in ppm. The Gastec hand pump is less subject to operator error.

Static Pressure Tip -- A static pressure tip is connected to the indoor pressure tubing. This allows the manometer to be used for measuring the updraft pressures in all oil-furnace flue-connector. The tip consists of a perforated, angled tube which fits into a 8mm (1/4") hole in the flue pipe and provides a reading of static pressure. A suitable tip is Dwyer Model A-303, which is designed for use with 3/16" flexible tubing, and contains a magnet to hold the tube in place during readings.

3. On-Site Procedures, Step-by-Step

PART ONE: CHIMNEY INSPECTION

The chimney inspection can begin before entering the house. A walk around a house gives a view of the chimneys, from all directions. Binoculars will assist in a closer inspection of the tops of chimneys, where most hazards are likely to be developing. Any potentially hazardous situations should be flagged on the form, for future reference. A convenient way to flag problems is to use a letter-number code: the letters are listed on the form (A = furnace, B = DHW, C = fireplace). There are twenty-one separate inspection items listed, in an attempt to provide a reference list of potential hazard sources. For example, A-7 would indicate that a gas furnace was attached to a masonry chimney where a lining (needed for safety purposes) is missing. Maintenance flag C-5 would indicate that the brickwork on the fireplace chimney, was in need of repair.

At all times, the intention should be to flag those problem areas which warrant some remedial action by the occupants of the house. A brief elaboration of the inspection items is provided below:

1. **Cap needs repair** -- could indicate that the chimney cap is cracked, broken, crumbling, or perhaps even missing. A seriously broken or crumbling cap can fall into the chimney opening and cause partial blockage. Rapid deterioration of caps may indicate condensation and freezing problems.

2. **Clearance insufficient** -- is worth noting in cases where a chimney is surrounded by much higher obstacles which might, under windy conditions, create down-drafts in the chimney. Most codes for chimney installation require that the top of any chimney be at least 60 cm (2 ft) taller than any obstacle within a 3 m (10 ft) radius. To be sure of avoiding downdrafting, a 12 metre (40 ft.) radius is better.

3. **Supports inadequate** -- could indicate that the chimney is leaning badly or appears about to fall over, or is inadequately braced for its height.

4. **Brickwork needs repair** -- could indicate sooting at various locations up the face of the chimney. Soot spots on chimneys indicate leaks in the wall. Another problem with brickwork is spalling or chipping off of bricks due to heavy moisture accumulation in a flue, with subsequent freezing and expansion pulling the bricks apart. Brickwork also may need repairing because the chinking in the mortar between the bricks is being forced out and is falling away. Many homeowners fail to recognize that chimney maintenance will be required every few years.

5. **Top sooted or stained** -- is an indication of a dirty burn or condensation. (Identifying an appropriate remedial measure requires further investigation.) It is often difficult to recognize this condition without getting on to the roof of a house and closely inspecting the chimney. Ideally, a chimney inspection should include looking down

chimney. Ideally, a chimney inspection should include looking down the flue, from above, while dropping a flashlight or trouble light to the base. Unfortunately, this kind of procedure is time-consuming, dangerous, and often impractical during inclement weather. For these reasons, the chimney inspection recommended for the Safety Check involves visual detection from the ground only. A roof inspection should be considered only when problems are already indicated.

6. **Lining missing (gas)** -- This is a concern, especially in colder regions where gas furnaces have replaced oil- or coal-burning appliances, and have been vented up large masonry chimneys without a lining. Sometimes the top of the chimney is fitted with a liner, but only for the first meter or so, giving the appearance, from the outside, that the chimney is properly lined. To properly inspect the chimney lining, it will be necessary to use the mirror inside the flue. A lining is essential for chimneys on exterior walls, and recommended for all chimneys with condensation problems.

7. **Lining needs repair** -- Again the mirror must be used to inspect the lining of a flue, although this is only a partial evaluation, at best. Fitting the mirror into the lining of a chimney can be a fairly time-consuming task. On many existing houses, it is possible to inspect the inside flue from the exterior of the home, by removing the ash clean-out, if it can be found at the base of the chimney. If the ash clean-out is already plugged and filled, or cannot be cleaned out or opened, this would warrant mention in the "Other Problems" section. If the lining cannot be inspected from the outside of the house, the inspection moves inside at this time. From inside the house, it may also be possible to use ash clean-outs to inspect masonry chimneys. In some cases, however, it will be necessary to remove the flue connector, from the vertical chimney, in order to obtain access. A ratchet is provided for this purpose and will almost always be required in the case of gas systems. Oil furnaces have flue connectors which can usually simply be pulled out from the wall. Once the flue connector is

removed from the vertical chimney, it also becomes possible to inspect the flue connector.

When inspecting tile lining, look for broken pieces in the ash clean-out. Gaps in the tile are also a problem, as they allow moisture to penetrate to the brickwork.

8. **Creosote excessive** -- This can be a hazard on wood-burning appliances. Thick, shiny accumulations of wood tars, on the interior linings, may indicate excess creosote. Most chimney sweeps will recommend a thorough cleaning of the chimney if the accumulations of soot and creosote exceed a thickness of 6mm (1/4").

9. **Flue wrong size** -- This notation is an indication that the flue connector is improperly sized for the BTU output of the appliance. Incorrectly sized flues are sometimes a problem in older homes, where a number of conversions have taken place. Tables indicating proper flue sizes, for various BTU outputs and chimney heights, have been provided in Section 8 of the CGA Natural Gas Appliance Installation Manual.

10. **Flue connector loose** -- is an inspection item that requires an examination of the flue connector, to ensure that it is correctly held together, piece by piece, and is securely fastened at both ends. Longer flue connectors should also be provided with hanging metal supports, every one to two meters.

11. **Flue connector corroded** -- This problem can be caused by a number of factors, including dripping rainwater entering the chimney, high humidity in the furnace room, condensation during start-up in a cold chimney, or condensation occurring at the chimney top, during cold weather, and then dripping back down to the flue connector. The corrosion can occur at the connection between the C-vent in the vertical chimney, or at the breech of the furnace. Severe corrosion could be an indication that the flue connector needs to be replaced.

Even for minor corrosion, this can be a preventative maintenance measure, if the cause of corrosion can be diagnosed properly.

12. **Damper imbalanced** -- The barometric damper on the flue connector of an oil furnace should be checked to make sure that it moves freely and easily, and that the pivots are well-oiled. The proper operation of a damper should be evident during the full-cycle observation of the furnace (at a later point). The damper should be closed or just slightly open when the furnace is off, but once the furnace is started up, there should be a noticeable increase in the opening at the barometric damper. A damper that is imbalanced, or stuck open, may allow too much air entry, lowering updraft pressures in the furnace and contributing to back puffing and sooting.

13. **Hood stained or rusted** -- The dilution air inlet of a furnace, and the hood on top of a gas DHW, should be examined for staining or rusting. Heavy staining at this location could indicate severe condensation problems in the flue connector. Water leakage creates long, drip-type stains. Another type of stain is created by continuous spillage or backdrafting of an appliance. The characteristic stain is of more even, dark, burned spots, or the melting of any combustible materials near this location (eg, melted grommets around the water piping on a hot water heater).

14. **Connector design problems** -- This is a reminder to make a quick check of the flue connector dimensions and geometry. The length of the flue connector and its slope should fall within the guidelines provided on Section 8 of the CGA Natural Gas Appliance Installation Manual. In all locations, the flue connector should be at least 150mm from combustibles, to ensure fire safety. B vents should be 75mm from combustibles.

15. **Fuel odors present** -- The human nose is a "sensitive instrument" and an essential part of your toolkit. It is usually possible to detect small fuel leaks, or minor amounts of combustion spillage, in a house

immediately upon entering. Experienced servicer's learn to trust their noses, in most situations. Gas combustion pollution has a distinctively humid, musty odour to it. Natural gas leaks smell like rotten eggs. Backpuffing and spillage from an oil furnace will leave a stale, burnt-sulphur odour. When servicer's inspect gas lines for leaks, they are most likely to use their noses as a first test, and then soapy water simply to confirm that a leak does in fact exist. Fuel leaks occur, most often, at the valves or major junctions in the gas line, or around the pilot light connection. If a leak is suspected, you can obtain a much better nose reading by smelling each join directly. If the occupants of the house have been complaining of fuel odors, there will almost certainly be a leak at some junction, and they should be encouraged to contact a licensed gas fitter.

16. **Blower compartment loose** -- If the door to the blower compartment is poorly fitted, loose, or missing, the furnace will likely depressurize its own room. On occasion, occupants or furnace servicer's will leave these door off, especially during the summertime, to assist in cooling the house. Under no circumstances, should such practices be recommended. On the inside of the framing of the blower compartment, there is usually a label advising against the removal of the door. If such a label is missing, or not clearly attached, a preventative measure would be to immediately apply a new label cautioning against such removal. (Over the next several years, it is likely that many furnaces will become fitted with interlock switches which will simply disable the blower if this door has been left partially opened or completely removed.)

17. **Filter plugged** -- a severely plugged air filter will prevent proper air movement through a forced-air system. The furnace may overheat. The furnace may also depressurize its own room, by increasing the amount of return air that is sucked around the edges of the filter compartment, or through leaks in the air plenums and furnace casings. Consequently, the more plugged the filter, the greater the effect of the blower on lowering pressures in the vicinity of the furnace.

Inspection of the air filter, prior to testing, will help to reveal whether such problems are already developing. Extremely dirty filters should simply be removed, and the occupants advised about maintenance measures.

18. **Burner dirty or sooted** -- Heavy sooting around the burner, or port on an oil furnace, is an indication of continued backpuffing at start-up. This may be a result of frequent backdrafting, or weak updrafts, or an imbalanced damper. There may be need for a delayed action oil valve, to ensure proper air flow prior to ignition. On an oil burner, it is also important to examine the air inlet ports, around the squirrel cage blower, that provides forced air for combustion. These inlet openings should be free of lint, dog hairs, and other such items. If there is any constriction, or blockage of primary combustion air feeds to a burner, the result may be poor combustion and sooting.

    On a gas burner, it is important to check the primary air intake openings at the near end of the venturi. The jets themselves should also be examined for accumulations of rust, soot, and other forms of dirt and contamination. Sometimes scaling or rusting of the heat exchanger will deposit metal on the burner jets, interfering with proper flame development. Dogs have often been known to lie against this part of the DHW because they enjoy the warmth, and in doing so can often plug the air supply with hairs, to the point where heavy sooting and CO production occur.

19. **Air supply plugged** -- The existing air supply inlets to the combustion appliances should be examined, to ensure that they are operating properly. In- line dampers should be examined, to see if air supply has been shut off. The openings should be checked, to be sure that occupants have not (at some time) stuffed rags, insulation or other objects into them, to prevent cold air pooling on floors. The exterior of air supply ducts should be examined, to ensure that screens or louvres have not been plugged by insects, dirt or other items.

20. **Inlet poorly located** -- The location of any air supply openings should be checked for essential problems, such as: a location inside a garage, or near any other source of pollution; a location too near to the ground, or in regions where snow cover could cause blockage; or a location under closed-in stairs, or inside a tight shed, where air supply to the inlet opening may be restricted.

PART TWO: FURNACE ROOM VENT PRESSURE TEST

The objective of PART 2 is to answer the question: Are exhaust systems in a house capable of creating dangerous backdrafting in the flue of a furnace or DHW?

The procedure is to create a number of potential "worst case" conditions in a house and, under these conditions to measure the total depressurization of the furnace room relative to outdoors. Depressurization is measured in Pascals of air pressure. The maximum depressurization obtained under each test condition is recorded, and compared to Table 2 on the reverse side of the Safety Check Form. The Table lists maximum allowable depressurization limits for various types of appliances and chimneys. If the depressurization recorded on the gauge exceeds the number on the Table, the house has failed the test.

The MAD limits are intended for conventional houses and conventional chimneys. Unless the Chimney Inspection has revealed unusual or problem situations, the limits will, in most cases, ensure safe operation of chimneys. In houses where pressures are marginally close to the maximums, some discretion on the part of the user is advised. Marginal situations may warrant a cautionary label, a warning to the occupants, and an explanation of how to avoid the 'worst case' conditions for that particular house.

PROCEDURES STEP-BY-STEP:

Close exterior doors, windows, interior doors:

The intention is to make the house envelope as tight as possible. After closing the exterior doors, enter each room of the house, to ensure that every window is tightly closed and latched. This procedure should be followed, even if the occupants have been requested to close windows prior to your arrival on- site. If only one window is left open, the tests results become invalid.

While checking each of the rooms of the house to ensure that windows are tight, also close the door into each room, unless the interior doorway provides a direct connection between the furnace chimney and either a cold air return or an exhaust fan. For example, most bedrooms in a house will be passive rooms, lacking any exhaust systems, and the doors must be shut. Kitchens, bathrooms, and laundry rooms, on the other hand, often contain exhaust fans, and should have their doors left open.

Turn off furnace, DHW, stove:

The object is to shut off the furnace and DHW so as to permit plugging of flues. Wood stoves should also be closed off as tightly as possible. Usually the best technique for shutting off gas appliances is to turn the valve at the appliance from ON to PILOT. This approach guarantees no accidental operation during the test, and allows you to later operate the appliance simply by adjusting this valve. In addition, you may choose to blow out the furnace pilot light at this time (to allow the heat exchanger to cool off in preparation for PART 3). More information on blowing out the pilot is provided in PART 3).

Almost all oil furnaces are provided with an electrical switch, to shut off the entire system. This switch is likely to be located close to the appliance, or on the way up the basement stairs.

If furnaces and DHW have been shut off, by means of pilot valves or electrical switches, it is useful (at this time) to turn the thermostats up, so as to ensure immediate full operation whenever the switches are re-set. This will expedite procedures in PARTS 4 and 5.

Set up tubing and gauge:

Early set-up of the manometer and tubing allows you to locate an appropriate place in the house for storage of tools and to allow the fluids in the manometer to achieve a stable condition.

The manometer should be located at a level in the house similar to the exit point for the outdoor pressure tubing. This allows the outdoor pressure tubing to remain relatively horizontal throughout its entire length, avoiding any pressure discrepancies inside the tube. If a pressure tubing exit point can be found in an area close to the furnace and DHW of the house, this is probably the best location. In most cases, however, the manometer will be set up on the first floor, to allow for easy exit through the mail slot, through weather stripping at the lower corner of a doorway, or around the edge of a sliding window that can be easily taped shut. Finding an appropriate exit location can be the most creative part of the Safety Check procedure!

The manometer gauge should first be leveled in an appropriate location and then zeroed (approximately), to ensure that the fluid levels are correct. Open the pressure ports on the inside of the manometer (clockwise) and attach two sections of tubing.

The indoor pressure tubing is normally marked with red tape and should be quick-connected to the left port of the gauge. Extend this indoor pressure tubing to a location close to the furnace.

The outdoor pressure tubing is marked with blue tape, and should be extended out the exit point from the house and into the yard. Once outside the house with the pressure tubing, there are two options:

1. If winds are less than about 15kph and not too gusty, it is usually possible to use a single pressure tap and thereby save time and effort. The end of the outdoor pressure tube should be located in a relatively sheltered location, 5- 10m away from the house. This "outdoor" end should be permanently fitted with a plastic collar, and a 0.5mm diameter, 100mm capillary tube, to dampen minor wind pressure variations. For a calm weather test, this single tube should be fitted with the windscreen cap.

2. If winds are gusty or strong, it will be necessary to extend pressure taps to all four sides of the house. The procedure is similar to that followed in the CGSB Fan Depressurization Test Standard. Additional lengths of tubing, and an octopus connector,can be used for this purpose. The outdoor pressure tube can be connected to the octopus, outside the house, and three additional lengths of tubing should be connected and stretched around to the appropriate sides of a house. Careful handling of the tubing is essential to avoid snags and time delays. Tubing materials must be specially selected not to crimp with usage, or crack in cold weather. An inside diameter of at least 5.0mm helps to avoid resistance from the extra length of tubing. The ends of each pressure tap should be taped at an elevation similar to the exit point from the home. Two 15m sections of tubing can be extended to each of the closest sides. A 30m section can be extended to the opposite side.

Close inlets: furnace room, house, fireplace:

Closing air inlets provides an additional safety measure and improves the reliability of test results. By closing inlets at this time, it will also be possible to determine if such inlets are essential for safe operation.

If inlets are equipped with shut-off dampers, these dampers should be shut as tightly as possible. This is usually the case with fireplace air supplies. Inlets in the furnace room, or fresh air supply to the house, are often not equipped with shut-off dampers and must be taped shut, at whatever location is convenient. Copious use of 120mm wide tape may be required, to ensure that inlets are sealed during the test.

Close chimneys: furnace, DHW, fireplace dampers:

The chimneys must now be sealed off from the house, to ensure that they do not continue to operate as an air exhaust or supply, during the air pressure measurement.

Fireplace chimney dampers should be shut as tightly as possible, using the chimney damper. The furnace and DHW flues can be temporarily sealed with the "failsafe" balloon flue-sealers. Do not plug flues by other means.

Fans off, covers removed:

Fans must all be turned off, so that the manometer can be zeroed under balanced conditions. Filters on the fan grilles should be removed, if possible, to add a margin of safety. Cleaning (or removing) lint filters on clothes dryers is also recommended. If the furnace has a continuously operating, low-speed blower system, turn this off as well.

Zero gauge:

The manometer can now be zeroed precisely. Ensure that the bubble-level has been properly leveled, and adjust the scale to ensure that the meniscus is precisely at 0. The direction of viewing can make a large difference in reading, so remember to line up the meniscus with its own reflection in the scale. If, at this time, it is difficult to zero the gauge, due to fluctuations in the fluid, the problem may be excessive wind effects. For an accurate test, the fluid levels should remain absolutely stationary. Adapt the outside pressure tubing for windy conditions, if zeroing problems persist.

Operate fans and record pressures:

Two-way fans, Exhaust fans, Blower:

The objective is to operate all potential exhaust systems in the house, and record the subsequent depressurization. Two-way fan pairs - such as air-to-air heat exchangers - are operated first. Switch these fans to high speed. If they are intended to operate in combination with a continuous furnace blower, turn the blower on to low speed. Their effect may be to pressurize or depressurize the house.

If the effect of these two-way fans is to **pressurize** the house, record the maximum pressurizations in the **Results Summary** using a + symbol (e.g. + 3.2 Pa.), and then turn down the fans to their minimum operating speed for the remainder of PART 2. On the other hand, if the effect of the two-way fans is to depressurize the house, record the maximum depressurization and leave the fans operating at high speed, since this is the "worst case" condition for chimneys.

Next, operate all the exhaust fans in the house simultaneously, at high speed. Include the range hood fan (if ducted outdoors), the stove top barbecue fan, the clothes dryer (if ducted outdoors), bathroom fans, the household vacuum (if the motor is located outdoors), and any special exhaust fans (like washroom or sunroom). Bathroom exhaust fans with timers are best taped on to avoid sudden, unknown shut-offs. The household vacuum system should be plugged into a central outlet.

In houses equipped with **air-to-air heat exchangers**, check to see if it is designed to defrost by operating only as an exhaust fan. If so, the heat exchanger system constitutes an exhaust system, and should be operated in this condition. To activate the defrost mode, on an air-to-air heat exchanger, adjust the set points on the temperature control (located near the fan) to room temperature.

With all exhaust fans operating, the maximum depressurization measured on the manometer should be recorded in the Results Section of PART 2, on the form opposite "FANS".

If the furnace blower has a manual switch that permits continuous high-speed operation, a second manometer reading should be made, after activating the blower switch. With all exhaust fans and the furnace blower operating at full speed, record the Pascals of depressurization opposite "BLOWER".

Fails? Inlets open, labels applied:

If any of the recorded pressures exceeds the maximum allowable depressurization (MAD) limits listed in Table 2, the house fails. In a failure house, the next step is to open the air inlets to the furnace room and/or to the house. (Fireplace inlets should be left closed.) The house pressures should be recorded once again, and noted opposite the "REDUCED PRESSURE" section of the Results Summary. At the same time as recording the reduced pressure, describe the measures taken to reduce pressures on the line beginning "RELIEF MEASURES TAKEN". (For example: RELIEF MEASURES TAKEN: "Unsealed duct into furnace room".) If inlets must be opened, because of failure pressures, they should be tagged with an appropriate label, at the same time as they are opened.

There are two cautionary labels that might be used on air supply inlets, in cases where houses have failed PART 2 of the Safety Check because of mechanical ventilation systems:

Caution: Avoid chimney failure. Do not block or restrict this opening.

or,

Caution: Outdoor air supply is essential for the safe operation of combustion appliances in this house. Labels should be dated and initialed. A phone number or a business card is also recommended.

If the opening of inlets does not succeed in lowering depressurization levels below the limits listed in Table 2, the house fails again. The Safety Check cannot proceed until a pass is achieved by balancing the ventilation system. This could involve such measures as installing additional make-up air supply, disabling one or more exhaust fans, or by turning off one or more exhaust fans and applying appropriate cautionary labels.

Once a house achieves depressurization levels low enough to pass the MAD limits, continue with PART 2. Exhaust fans must be left operating for the entire Safety Check, (PARTS 2, 3, 4 and 5).

FIREPLACE OPTION:

Prepare small fireplace: window open, chimney open, air supply open, fireplace doors open, burner high, check draft, window closed:

The objective is to add the hot air exhaust, from an operating fireplace, to the total exhaust from mechanical exhaust systems. If the house has two fireplaces, begin with the smaller fireplace, or the most frequently operated fireplace.

Since the house is already under depressurization, via mechanical exhaust systems, it is important to open an exterior door or a window prior to lighting the fireplace. The fireplace chimney damper is then opened, as well as any direct air supply intended for fireplace operation.

If the fireplace has doors, it is initially tested with doors open. The intention is to see if the fireplace is safe to operate with open doors, since this will often be a householder's preferred choice.

The propane stove is mounted inside the combustion chamber of the fireplace. It is then lit with the butane lighter and adjusted to the maximum burn rate. Check for proper draft, with the smoke pencil, or by holding the butane lighter inside the upper edges of the fireplace opening. If any backdraft is occurring, under these conditions, the chimney is suffering from blockage, a dirty flue, or down-wind problems, and should not be tested further. Otherwise, allow the chimney a minute or two to fully warm up, and then shut the outside window or door.

Check fireplace for spillage:

Immediately after closing the outside window or door, it will be necessary to check the fireplace itself for any signs of spillage. Often, if a house is close to the failure depressurization limits, the fireplace will spill even at high burn rates. Use the butane lighter along the upper edge of the fireplace opening, to determine if air currents are moving into the fireplace and up the chimney, or down the chimney and out into the room.

If spillage is occurring, first try closing any fireplace doors and checking again for spillage. If spillage cannot be eliminated, turn off the propane stove, label the fireplace for additional air supply, and move on to PART 3. If no spillage occurs, read the manometer and record the house depressurization level in the Results Summary. If this depressurization level exceeds the maximum allowable depressurization (MAD) limit, the failure should be noted and labels applied to the fireplace.

On occasion, a house will have more than one fireplace. A house with two fireplaces must also be checked with both fireplaces operating simultaneously. After completing the above test procedures, with the smallest fireplace, simply repeat all these steps for the second larger fireplace. During this process, leave the first fireplace operating at full burn. If both fireplaces are identical, consider the "smaller" fireplace to be the most frequently operated one. If you lack a second propane stove for the second fireplace, use crumpled newspaper.

PART THREE: HEAT EXCHANGER LEAKAGE TEST

The Heat Exchanger Leakage Test is essentially an airtightness test of the furnace heat exchanger. The objective is to determine if any significant amount of cross-contamination might occur between combustion gases and circulating household air, or whether spillage might occur due to the entry of forced air into the combustion chamber.

The Test is designed in such a way that it is not essential for the tester to be properly certified, or to have obtained a provincial ticket for working on this type of appliance. The appliance is observed as it operates, with the blower on MANUAL setting. The test does not involve any dismantling, adjusting or calibration of controls on the appliance, other than what is required to manually operate the circulating blower. There is, however, a necessity to blow out - and later re-light - the pilot light over a gas furnace. Non- certified individuals may require special authorization from provincial gas authorities to re-light pilots.

The inspection procedure, for detecting cracks and leaks in heat exchangers, requires a visible check for air flow into, or out of, the combustion chambers (or ports). Large relative pressure differences -- in the range of 50-75 Pa -- occur across the heat exchanger when a circulating blower is operating. The blower creates considerably higher pressures in the forced air system than exist in the combustion chambers of the heat exchanger. Consequently, if any leaks or cracks do exist in the heat exchanger, and the blower is operating, we would expect to have significant amounts of air blown into the combustion chambers. If the chimney is plugged at the same time and the heat exchanger is kept cold, then any air movement out of the combustion chambers, while the blower is operating, will indicate leakage.

A heat exchanger test, based on these principles, must be completed with the chimney plugged and the heat exchanger cold.

GAS FURNACE

Furnace Pilot light off:

If the pilot light has not already been blown out at the beginning of Test 2, it should be blown out at this time. The pilot light must be shut off, to ensure that no heat is added to the heat exchanger, which might create convection currents and make the identification of leakage through the heat exchanger more difficult. The reason for blowing out the pilot, rather than just turning off the valve entirely, is to ensure that the safety controls on the furnace are operating properly. After blowing out the pilot light, the thermocouple next to the pilot will cool and subsequently shut off the main gas valve. This process can take up to 3 minutes. It is usually possible to hear when the valve is turned off because the gas hissing will stop and a click will occur in the main gas valve. Be sure, during this period, not to light a flame near the furnace.

If a thermocouple fails to shut off the gas valve, after three minutes of waiting, then it is a deficient part and must be replaced. The main gas valve can be manually shut off and a maintenance flag recorded, to advise the householder of essential maintenance requirements.

Flue still plugged:

If the chimney is not still plugged (from Part 2), it should be plugged at this time. The flue sealer can be inserted through the dilution air inlet and up into the main flue. Inflate the balloon in the flue. After the balloon is inflated, a smoke pencil can be used at the dilution air inlet to ensure that no updraft exists.

Prepare equipment: smoke ready, light on:

A glass smoke pencil tube should have both ends snipped off with wire snippers, or broken off using pliers, or fork tines. One end of the tube is inserted into the rubber squeeze bulb. The other end is inserted into the flexible tubing of the extension kit. The penlight should be turned on at this time.

Smoke check ports with blower off: bottom, top:

Use the extension smoke pencil to insert a cool white stream of smoke opposite each of the port exits and entry points on the furnace. The smoke should curl and remain relatively stationary at this time. Sometimes there is residual heat in the heat exchanger, which results in small convection currents pulling air in at the lower ports (alongside the gas jets), and out at the top ports. These convection currents can be misleading, and that is why it is a good idea to evaluate the extent of air flow at this time, under non-operating conditions.

If considerable convection currents exist at this time, the Test should not be completed until the heat exchanger has been allowed to cool further. Rapid cooling of the heat exchanger can be effected by operating the furnace blower on MANUAL. Since this blower will already have been operated, in manual condition during Test 2, it is likely that the heat exchanger will now be close to room temperature.

Test leakage: blower on, repeat smoke check:

Manually operate the furnace blower.

Re-check for air movement out of (or into) the combustion ports of the heat exchanger, at the bottom and top of the furnace. If any amount of significant air movement now exists at these locations, and did not exist previous to the operation of the blower, it is safe to assume that some leakage area exists in the heat exchanger. If a leak occurs in only one section of the heat exchanger, then the air flow will be confined to the ports connected to that section.

Leakage areas smaller than a penny will cause a flow of air to move out at a slow, but steady, pace. Openings larger than a penny typically create so much air flow, out of the heat exchanger, that the smoke trail from the smoke pencil will be blown apart in the wash. Evaluating the extent of leakage in the heat exchanger from the disruption of the smoke is a judgement call. At this time, caution is advised, since many heat exchangers experience small amounts of leakage. Only if the flow out of the heat exchanger is steady and significant, should the furnace fail the Safety Test.

During the test for heat exchanger leakage, be sure that the extension is used to insert smoke right inside the ports of the heat exchanger: there must be no possibility of distortion of the smoke trail because of normal air leakage in the furnace casing or blower compartment.

Reset furnace: blower off, chimney open, pilot lit:

After completing the smoke pencil analysis, the blower can be reset to automatic operation, the flue unplugged, and the pilot relit. Relighting pilots requires that the gas valve be pressed down and the butane lighter used to light the flame. After lighting the pilot, the valve must remain depressed for a period of approximately one minute, in order to allow the thermocouple to warm up enough to maintain gas flow.

OIL FURNACE

Ensure burner off:

If the oil burner has not already been turned off at the beginning of Test 2, it should be turned off at this time. The burner must remain off, to ensure that no heat is added to the heat exchanger, which might create convection currents and make the identification of leakage through the heat exchanger more difficult.

Flue still plugged:

If the chimney is not still plugged for Part 2, it should be plugged at this time. The flue sealer can be inserted through the barometric damper . Inflate the balloon in the flue. After the balloon is inflated, a smoke pencil can be used at the dilution air inlet to ensure that no updraft exists.

Prepare equipment: smoke ready, port open:

A glass smoke pencil tube should have both ends snipped off. One end of the tube is inserted into the rubber squeeze bulb. The inspection port on the face of the front furnace should be swung, or propped, open - to create a 5-10mm wide crack leading directly into the combustion chamber.

Smoke check ports with blower off: bottom, top:

Use the smoke pencil to insert a cool white stream of smoke into the crack at the inspection port of the furnace. The smoke should curl and remain relatively stationary at this time. Sometimes there is residual heat in the heat exchanger, which results in small convection currents pulling air in at the lower burner openings, and out at the port areas. These convection currents can be misleading, and that is why it is a good idea to evaluate the extent of air flow at this time, under non-operating conditions.

If considerable convection currents exist at this time, the Test should not be completed until the heat exchanger has been allowed to cool further. Rapid cooling of the heat exchanger can be effected by operating the furnace blower on MANUAL. Since this blower will already have been operated in manual condition during Test 2, it is likely that the heat exchanger will now be close to room temperature.

Test leakage: blower on, repeat smoke check:

Manually operate the furnace blower.

Re-check for air movement out of (or into) the inspection port of the furnace. If any amount of significant air movement now exists and did not exist previous to the operation of the blower, it is safe to assume that some leakage area exists in the heat exchanger. Leakage areas smaller than a penny will cause a flow of air to move out at a slow but steady pace. Openings larger than a penny typically create so much air flow, out of the heat exchanger, that the smoke trail from the smoke pencil will be blown apart in the wash. Evaluating the extent of leakage in the heat exchanger, from the disruption of the smoke, is a judgement call. At this time, caution is advised, since many heat exchangers experience small amounts of leakage. Only if the flow out of the heat exchanger is steady and significant, should the furnace fail the Safety Test.

During the test for heat exchanger leakage, be sure that the extension is used to insert smoke right next to the inspection ports: there must be no possibility of distortion of the smoke trail because of normal air leakage in the furnace casing or blower compartment. If necessary, shield the smoke form drafts emanating around the plenum joints.

Reset furnace: blower off, chimney open, port closed:

After completing the smoke pencil analysis, the blower can be reset to automatic operation, the flue unplugged, and the inspection port closed.

PART FOUR: FURNACE ROOM SPILLAGE CHECK

The purpose of PART 4 is to determine if unacceptable quantities of flue gas spillage occur during operation of the furnace or water heater. Even in cases where no problem exists from depressurization in a house, there may still be design flaws, or a partial blockage of the chimney, that can result in spillage - causing indoor pollution from combustion by-products. Overfiring of the appliance, or large leaks in the heat exchanger, can also cause spillage to occur through the dilution air inlet on gas furnaces. The Spillage Check will ensure that none of these conditions exist. For gas appliances, it will also ensure a reasonable margin of safety from hazardous spillage, by calculating the percentage of overfiring, and by measuring carbon monoxide concentrations in the flue gas.

PROCEDURES STEP-BY-STEP

Ensure continued operation of fans and fireplaces:

The 'worst case' conditions of PART 2 will be continued for PART 4.

During the Spillage Check, leave mechanical exhaust systems operating at full speed and fireplaces at full burn (unless, for some reason, the systems have been labeled and should not be operated in these conditions). This set-up will provide some degree of house depressurization, and therefore simulates 'worst case' conditions for the operating appliances, especially during the start-up phase.

Furnace operation: stand aside, turn on burner:

Prior to operating the appliances, it is recommended that you check the existing draft in the chimney. This can be done right after the chimney has been unplugged, by using a butane lighter or a smoke pencil. If a backdraft condition exists in the house, then it is recommended that you stand aside from the dilution air inlet as the gas valve is turned on. There will likely be a considerable amount of spillage and backpuffing during start-up. In such situations, and it is unwise to expose yourself to heat, flames or spillage gases as the furnace tries to re-establish a proper updraft. Once draft has been checked and appropriate safety precautions taken, the burner on the furnace should be turned on.

Observe and time spillage at hood, damper, joins, DHW:

Once the furnace has begun operation, the smoke pencil or butane lighter can be used to check for spillage around the dilution air inlet of a gas furnace, or around the burner and inspection port of an oil furnace. If any amount of spillage is observed, it should also be timed.

For the purposes of this field evaluation, any furnace that is observed to spill continuously, for a period greater than 15 seconds, is deemed to have failed PART 3. If no spillage is evident, immediately around the burner or the dilution air inlet, use the butane lighter or the smoke pencil extension kit to check for spillage along the combustion ventilation system. Check along joins in the flue connector, the barometric damper, at the junction of the DHW vent, at the DHW draft hood itself, and at the connection between the flue pipe and the vertical chimney.

Recheck spillage after blower operates:

Let the furnace burner run until the circulating blower begins to operate.

Once the blower has started to operate, repeat the check for spillage at the dilution air inlet, and around the burner combustion air inlets.

Clock Gas Meter: Record seconds: cubic feet: BTU/hr:

With the furnace operating, and all other gas appliances not operating, it is possible to clock the gas meter and calculate the actual firing rate. Overfiring of residential gas furnaces is not common, since the pressure regulators and orifice are factory set. Usually the furnaces are underfired intentionally by 5 or 10 percent. A test for overfiring is probably warranted only if no other explanation exists for spillage occurrences. A test of manifold pressure is also recommended in such circumstances if the tester is suitably trained in this procedure. In any case, it is possible for all persons to determine overfiring problems using the following procedures.

Leave the furnace operating. Ensure that the gas range, gas water heater, and any other gas appliances are NOT operating. (Pilot lights can be left on.) Observe the gas meter as it turns, and note the value listed for one complete turn on the smallest dial. Most meters are so calibrated that one complete turn equals either a half, one or two cubic feet.

Time the seconds required for the dial to record 1 cubic foot of gas consumption. Calculate the Thousand BTU/hr input of the furnace by dividing the seconds into 3,852. This calculation is detailed for reference below.

One cubic foot of gas contains 1070 BTU, or 1.07 Thousand BTU. Therefore:

$$\text{THOUSAND BTU/HR. INPUT} = \frac{\text{"Seconds per hour"} \times \text{"BTU per ft}^3\text{"} \times \text{"ft}^3\text{"}}{\text{seconds}}$$

$$= \frac{3600 \times 1.07 \times 1}{\text{seconds}}$$

$$= \frac{3852}{\text{seconds}}$$

Compare this actual firing rate with the nominal firing rate listed on the furnace name plate. If the ACTUAL firing rate is greater than the NOMINAL firing rate, calculate the percentage overfiring using the following equation:

$$\text{Percentage overfiring} = \frac{\text{ACTUAL} - \text{NOMINAL}}{\text{NOMINAL}} \times 100$$

If the percentage overfiring is more than 10%, the furnace fails PART 4.

Sample Gas Furnace CO:

The carbon monoxide (CO) content of the flue gases, on a gas-fired furnace, can be sampled by using the hand pump and detector tube. The less CO in combustion gases, the less hazardous will be any spillage occurrences. The furnace should be running for at least one minute prior to sampling. Insert the tube into a combustion port by inserting the hand pump into the dilution in opening. The end of the tube should be held in the center of the port to capture 100% combustion gases. After pumping the required amount of gas through the tube, read the concentration of CO, in parts per million (ppm).

If the ppm concentration is greater than 75 ppm, the furnace warrants further investigation.

Levels of CO up to 400 ppm are allowable under the Canadian Gas Association certification test procedures. However, field testing of typical furnaces has indicated that levels of CO over 75 ppm, before dilution, are usually an indication of poor air mixing, flame impingement, or other problems.

Measure Oil Chimney Draft:

On oil furnaces, the barometric damper should now be open more widely than during the Chimney Inspection of PART 1. To ensure that the damper has been adjusted within safe limits, use the manometer to measure the chimney draft experienced by the furnace. Punch a 1/4" hole - or use any existing hole - in a straight section of the flue connector, midway between the furnace and the barometric damper. The indoor (red) tubing from the manometer can be temporarily fitted into the static pressure tip and then inserted into the hole in the flue connector. Return to the manometer, temporarily disconnect the outdoor pressure tap (blue), and read the pressure difference.

A properly balanced furnace damper should allow an updraft of between 5 and 9 Pascals. Higher readings indicate inefficient and costly operation. Lower readings create possibilities for spillage and backpuffing, and result in a FAILURE for PART 4. Before proceeding, detach the static pressure tip, re-attach the outdoor pressure tap, and ensure that the manometer has returned to its original reading.

Operate DHW: turn on burner, check spillage:

With all exhaust systems in the house operating, including the furnace, the DHW should be operated. It is usually simplest to operate the DHW by turning the gas valve to ON and the thermostat to high right, at the water heater. On an oil DHW, simply turn up the thermostat. In cases where the thermostat is not accessible, and it is otherwise not easy to activate the DHW, running a hot water tap at full volume should quickly achieve results. Once the DHW has begun to operate, a spillage check should be completed, in a similar fashion to the furnace check. Spillage, for period greater than 15 seconds, once again constitutes a failure condition.

PART FIVE: FIREPLACE VENT PRESSURE TEST

The Fireplace, Room-Vent-Pressure-Test follows a similar procedure to the Furnace Room, Vent-Pressure-Test (PART 2). The intention is to determine if, under 'worst case' conditions, the depressurization of the fireplace room is likely to result in hazardous spillage, or backdrafting, conditions. Table 2, provided on the reverse side of the Safety Checklist, also provides maximum depressurization allowances of fireplaces. When this limit is exceeded, the house fails PART 5 of the Safety Check. These maximum allowable limits do not guarantee safe operation for fireplaces in all houses. For the great majority of the houses passing the test, however, there is very little likelihood of any hazard developing, under normal house operating conditions.

Ensure continued operation: fans, furnace, DHW, fireplace:

In a similar manner to the end of PART 4, all the exhaust fans, furnace, and DHW should be operated or left operating. If there are two fireplaces, the unit which is not undergoing a test, at present, should be left operating, as well.

Relocate indoor tube to fireplace room and check manometer:

The indoor pressure tubing (that terminated in the furnace room for PART 2, 3 and 4) should now be relocated to the fireplace room.

Prepare small fireplace: burner off, air inlets open, chimney damper closed, fireplace doors open:

In preparing the fireplace room for the Vent Pressure Test, the propane burner can now be shut off. Air inlets into the fireplace opening should be left wide open. The chimney damper should be closed as tightly as possible, and any fireplace doors left open, (unless already labeled otherwise).

Record pressure:

The maximum depressurization in the fireplace room should be recorded in the results section of PART 5. If this pressure limit exceeds the limit for fireplaces, the house fails PART 5. If the furnace has been turned off prior to the start of PART 5, be sure that both the furnace and its blower are operating before depressurization levels are recorded.

Whenever a fireplace fails PART 5 of the Safety Check, the next step is to determine exactly what conditions, in the house, will allow the fireplace to be operated safely. This requires that the tester undertake a series of sub-routines, each of which should have the effect of lowering the total depressurization experienced by the fireplace. Once the level falls within acceptable limits, the fireplace can be passed, with the appropriate cautionary labels affixed to ensure that it is only operated under these "safe" conditions. The sub-routines may, or may not, apply to the particular house in question. Possible sub-routines are briefly described as follows:

1. Open inlets to the furnace room and to the house. If these inlets exist, and if they have been taped shut, the inlets can now be opened

and the total depressurization recorded once again. If the pressure level has now become "safe", the inlets should be labeled and PART 5 will be concluded.

2. If failure conditions persist, any doors on the fireplace should be shut. The indoor pressure tap which terminates in the fireplace room should now be relocated so as to terminate inside the fireplace itself. The tubing can normally be inserted through the up-draft air openings or cracks at the lower edge of the fireplace doors. Under these new conditions the pressure should be re-recorded, in the result section of PART 5, and the appropriate labels applied.

3. If failure conditions persist, and another fireplace is currently operating in the house, this other fireplace should now be shut off. With the other fireplace inoperative, pressure should be re-recorded and appropriate labels applied.

4. If none of the above options succeeded in lowering the fireplace room pressure to an acceptable level, it will be necessary to open a nearby window for this purpose. A window should be incrementally opened and the gauge rechecked until the pressures become acceptable. At this point, the dimensions of this "relief opening" should be recorded (in millimeters height by millimeter width) on the Results Summary of PART 5.

Prepare large fireplace:

In houses where two fireplaces exist, the Vent Pressure Test can be repeated for the second fireplace. For this purpose, the small (or most frequently operated) fireplace which was originally tested, should be set up and operated at full burn. The large fireplace can then be prepared, operated, and tested, by repeating each of the steps in PART 5. A second set of check-off boxes is provided, on the form, for this purpose.

COMPLETION

A complete Checklist is required to ensure that the house is safe and returned to proper operating conditions. Ensure that flues are open on each appliance, and that all the thermostats and switches have been reset.

Fresh air inlets, which are still taped shut or closed, should be untaped or returned to a normal condition.

The furnace should be allowed to operate for a full cycle, to ensure proper functioning of all components.

RESIDENTIAL COMBUSTION SAFETY CHECKLISTS

APPENDIX II

THE CHIMNEY SAFETY TEST

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Prepared for:

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

by:

Sheltair Scientific Ltd.

March, 1985

APPENDIX II

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AN INTRODUCTION TO THE SAFETY TEST

The Chimney Safety Test (or Safety Test for short) is for use by householders who want to know whether hazardous chimney backdrafting or spillage might occur in their house. Chimney backdrafting is a condition where the normally upward flow of air and gases in a chimney is reversed, and the chimney begins to bring air into the house. Chimney spillage is a condition where the chimney is incapable of exhausting the entire quantity of combustion gas, and consequently some amount of gas spills from the chimney into the furnace room. In either case, the result can be indoor air pollution, and a risk to health.

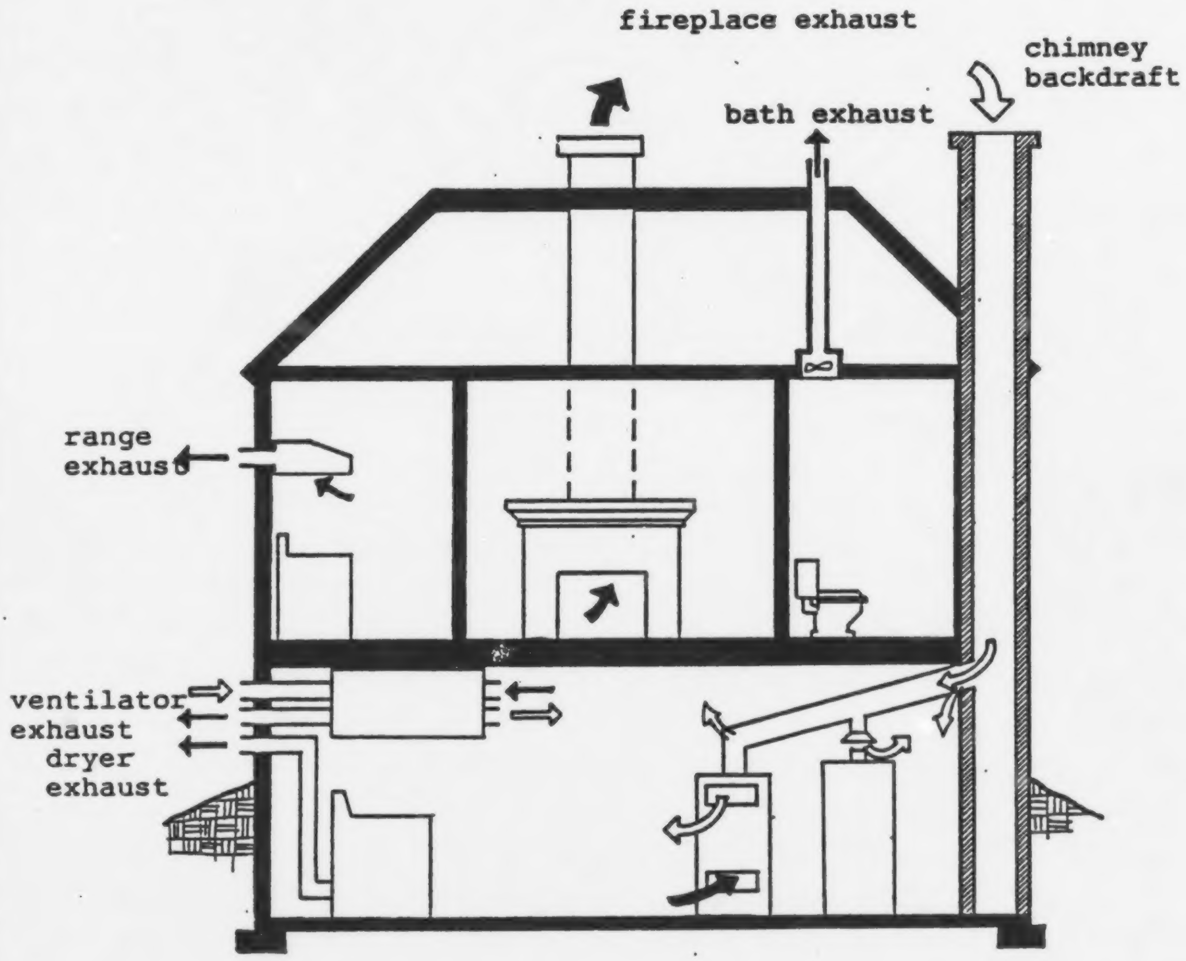
Chimney backdrafting sometimes occurs because air pressures inside a house are low relative to the outdoors. Low indoor pressures create a kind of suction at the bottom of a chimney. If indoor pressures are significantly lower than the outdoors, the chimney flow reverses.

Low indoor air pressures are created when a house lacks sufficient openings to replenish air exhausted by exhaust systems such as exhaust fans, fireplaces, furnaces, and hot water heaters. Most houses have plenty of fresh air openings into the house, due to the many random holes and cracks that exist in the walls and ceilings and around leaky windows and doors. Many houses also have specially installed fresh air supply inlets, ensuring that air supply is always sufficient to meet the needs of exhaust systems.

In some cases, however, make-up air supply may be inadequate. This can happen when houses are tighter than average, or when air supply requirements are higher than average due to powerful or numerous exhaust systems.

The Safety Test will allow you to determine if additional air supply is required for safe operation of chimneys in your house. You will intentionally create the worst possible situation for your house, and then

Figure 1


fireplace exhaust
chimney backdraft
bath exhaust
range exhaust
ventilator exhaust
dryer exhaust

CHIMNEY BACKDRAFTING OCCURS WHEN HOUSE EXHAUST EXCEEDS MAKE-UP AIR SUPPLY check draft in the chimney. If the chimney shows no indication of backdrafting, the house should be fit for occupancy under normal conditions.

If backdrafting occurs, two additional steps will be required. First, you must apply cautionary labels to warn against actions that might create backdraft conditions; and second, you must obtain expert assistance in balancing ventilation systems in your house.

The Safety Test will also assist you in checking for spillage problems. Spillage of combustion gases can be caused by a number of factors, such as a partial blockage of the chimney opening, a poorly designed chimney, or a cracked or leaky furnace. Low indoor air pressures can also provoke spillage problems.

If your chimney shows no indication of spillage during this test, the chimney is probably operating safely. Regular maintenance of the chimney will still be required, and during the process of testing your house, you will be asked to complete a brief inspection of the chimney to identify signs of future problems.

The Safety Test is a simple procedure that has been designed to work on most houses with conventional heating systems. Occasionally, it may be inadequate to deal with the unique characteristics of a particular house. For example, the Safety Test is not presently designed for use on a converted furnace where an oil burner has been replaced by a gas power-burner.

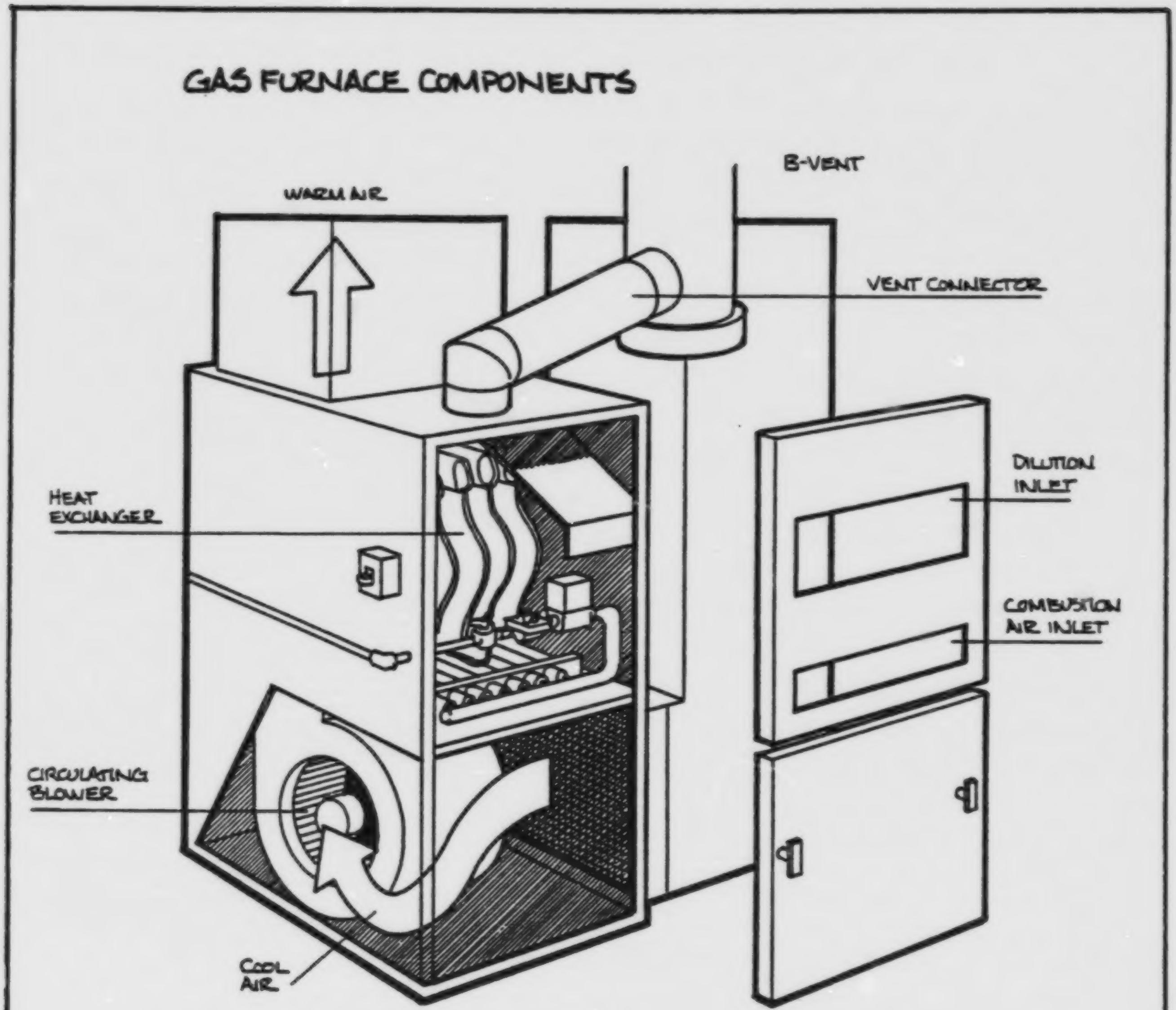
If difficulties are encountered in applying the Checklist, or if problems are identified by the Checklist, it will be necessary to contact a specialist and request assistance. A more complex version of this Checklist has been developed for use by tradespersons and technicians.

More information on how to cope with problems in your house can be obtained in the "Where to go from Here?" section that follows the test procedures.

Time requirements for completing this Safety Test will vary, but most houses can be checked in 30-40 minutes. If problems are encountered, you may require an additional half-hour. No special skill or experience will be needed. No special equipment is required either, although a butane lighter (throwaway type) will help make the test more convenient.

By completing a Safety Test on your house, you are making an excellent investment in your own health and safety. Recent studies have shown that many houses in Canada are currently suffering from indoor air pollution from combustion appliances such as furnaces and water heaters. Often, the occupants of a house may be completely unaware of a problem, failing to recognize that such symptoms as headaches, high humidity, stale air or odors, can be attributed to an improperly functioning chimney. Even if such symptoms are not present, the Safety Test is still worthwhile. An imbalanced ventilation system in a house may be an accident waiting to happen -- waiting for a particular combination of weather and house operating conditions. All houses with chimneys are good candidates for a safety test. Houses that have been airtightened, or have recently installed exhaust fans or fireplaces, are particularly susceptible to backdrafting problems.

Figure 2


GAS FURNACE COMPONENTS
B-VENT
WARM AIR
VENT CONNECTOR
HEAT EXCHANGER
DILUTION INLET
COMBUSTION AIR INLET
CIRCULATING BLOWER
COOL AIR

A SUMMARY OF WHAT'S INVOLVED

The Safety Test consists of ten separate steps, each described on a separate page. Use the check-off squares to keep track of your progress at each step. The list of steps below provides a quick summary of what's involved:

Step 1: Choose a calm, cool day.

Step 2: Inspect the chimneys and flue connectors.

Step 3: Prepare the house for testing.

Step 4: Operate exhaust fans and check the chimney draft.

Step 5: Operate the furnace blower and check again.

Step 6: Light a fast fire and check all the chimneys.

Step 7: Operate the gas furnace and check for spillage (or a poor flame).

Step 8: Operate the gas hot water heater and check again for spillage.

Step 9: Check fireplace for spillage as the fire dies down.

Step 10: Return the house to normal operating conditions.

STEP 1 CHOOSE A CALM, COOL DAY FOR TESTING.

During testing, it should be colder outdoors than indoors, but not too much colder. Do not test if temperatures are below freezing.

Local winds must be less than 10kph at the time of testing. No wind is best.

Winds are often calmer at night or in early morning; wait for a calmer day if necessary. (Check the TV or call the Weather Office.)

STEP 2 INSPECT YOUR CHIMNEYS AND FLUE CONNECTORS.

Preventative maintenance measures are the best way to avoid serious accidents with chimneys. Begin your inspection outside the house. Look up at the tops of the chimneys. Binoculars can help.

Chimney tops should be well clear of any obstacles that might create turbulent winds. A rule of thumb is to keep the chimney at least two feet above any obstacles within a ten-foot radius. Chimney extensions often help to solve problems of poor draft or wind downdrafts.

The cap of the chimney should be in good conditions. Cracking or crumbling masonry caps are a hazard because pieces can fall down the flue and cause blockage. Metal chimney caps should be free from heavy sooting, staining, birds' nests, or any other indications of problems.

Brickwork of the vertical chimney should be in good repair. Look for problems from mortar missing between the bricks, or from spalling and breaking away of brickwork, which often is an indication of excess condensation inside the chimney. All brick chimneys will require periodic repointing and repair.

Look for indication of a metal lining in masonry chimneys. Gas furnaces require metal linings in masonry chimneys for best performance. In areas of the country where winter temperatures are typically below freezing, a lining is almost always recommended. It is essential in cases where the chimney runs up the exterior side of the house. You can look inside (later) to determine if the lining at the top of the chimney continues throughout the full length.

Examine the tops of fireplace chimneys as well, while outside the house. Spark screens or caps must be kept clear of soot and cinders to ensure proper draft.

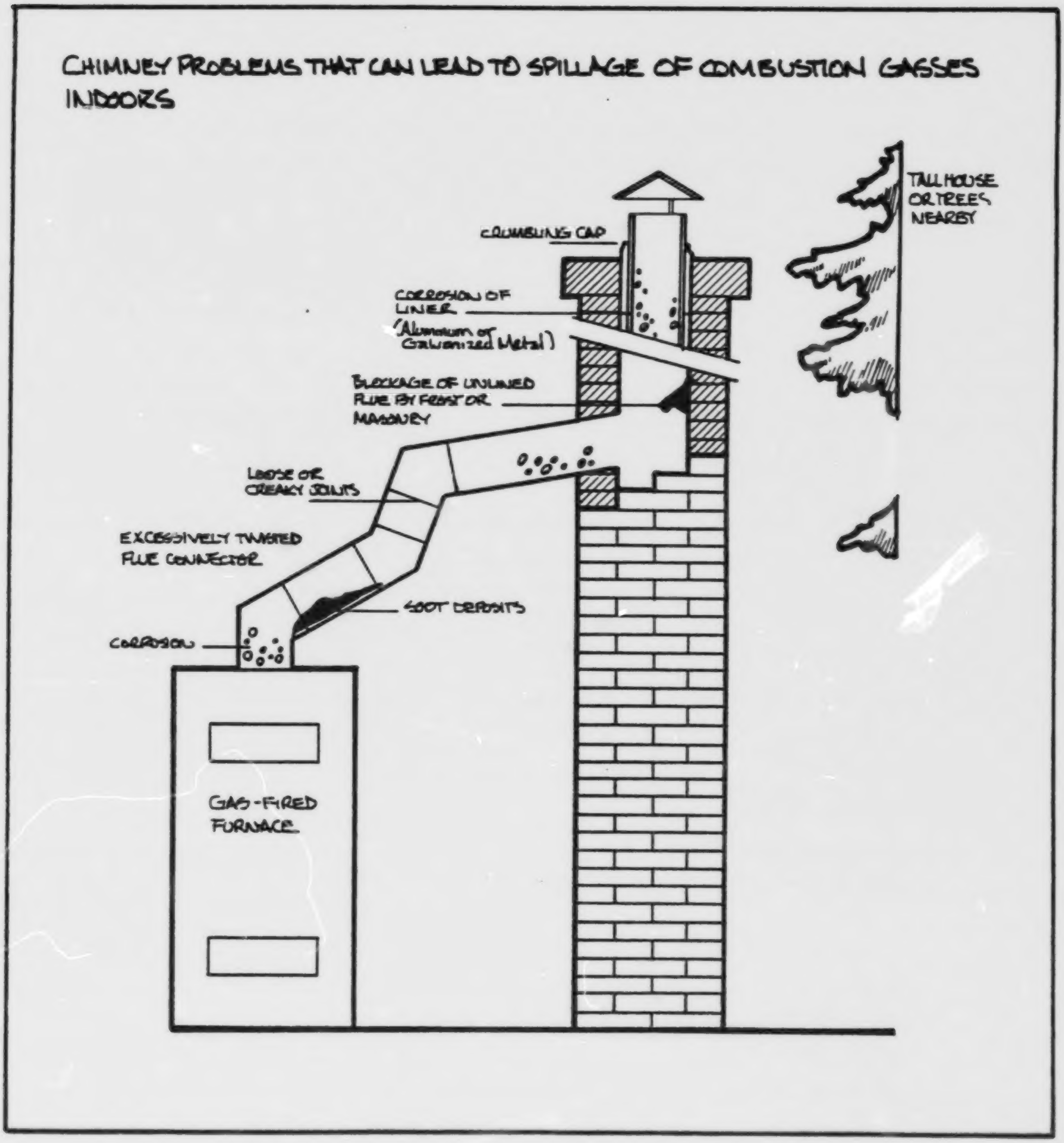
Look for ash cleanout doors at the bottoms of chimneys and ensure that these are properly cleaned out. Many exterior masonry chimneys have an ash cleanout accessible from the outside of the house, close to ground level. If the ash cleanout is not accessible from the outside of the house, try indoors.

The small metal door of the cleanout should be lifted off its metal supports, and the accumulated soot, or loose masonry , cleaned out. Heavy pieces of mortar or clay tile in the cleanout area indicate deterioration of the chimney lining or cap and suggest a need for a more thorough examination by a chimney specialist.

Use a flashlight to check the inside of any fireplace opening. Open the chimney damper and look up the flue. If soft, sooty accumulations on the lining of the fireplace chimney are deeper than 6-8mm (1/4"), then it is probable that the chimney requires a proper sweeping.

A hand-held mirror can be used to look for chimney blockage. Insert the mirror through the damper as far as the vertical section of flue, and look for a square of daylight while twisting the mirror. Wear gloves and an old shirt for this operation.

Figure 3


CHIMNEY PROBLEMS THAT CAN LEAD TO SPILLAGE OF COMBUSTION GASSES INDOORS
CRUMBLING CAP
CORROSION OF LINER (Aluminum or Galvanized Metal)
BLOCKAGE OF UNLINED FLUE BY FROST OR MASONRY
LOOSE OR CREAKY JOINTS
EXCESSIVELY TWISTED FLUE CONNECTOR
SOOT DEPOSITS
CORROSION
GAS-FIRED FURNACE
TALL HOUSE OR TREES NEARBY

Examine the flue connector that attaches your furnace to the vertical chimney. The flue connector should be solidly supported and tightly fitted at both ends. Each of the sections should be screwed together.

Check for signs of spillage or backdrafting around the dilution air inlets on the furnace and water heater, and all along the flue connector.
Heavy sooting, staining or burnt areas (especially around the top of a water heater) are all indications that hot gases might be spilling into the furnace room. (An exception is evidence of dripping on systems that lack a raincover at the chimney top.)

STEP 3 PREPARE THE HOUSE FOR TESTING.

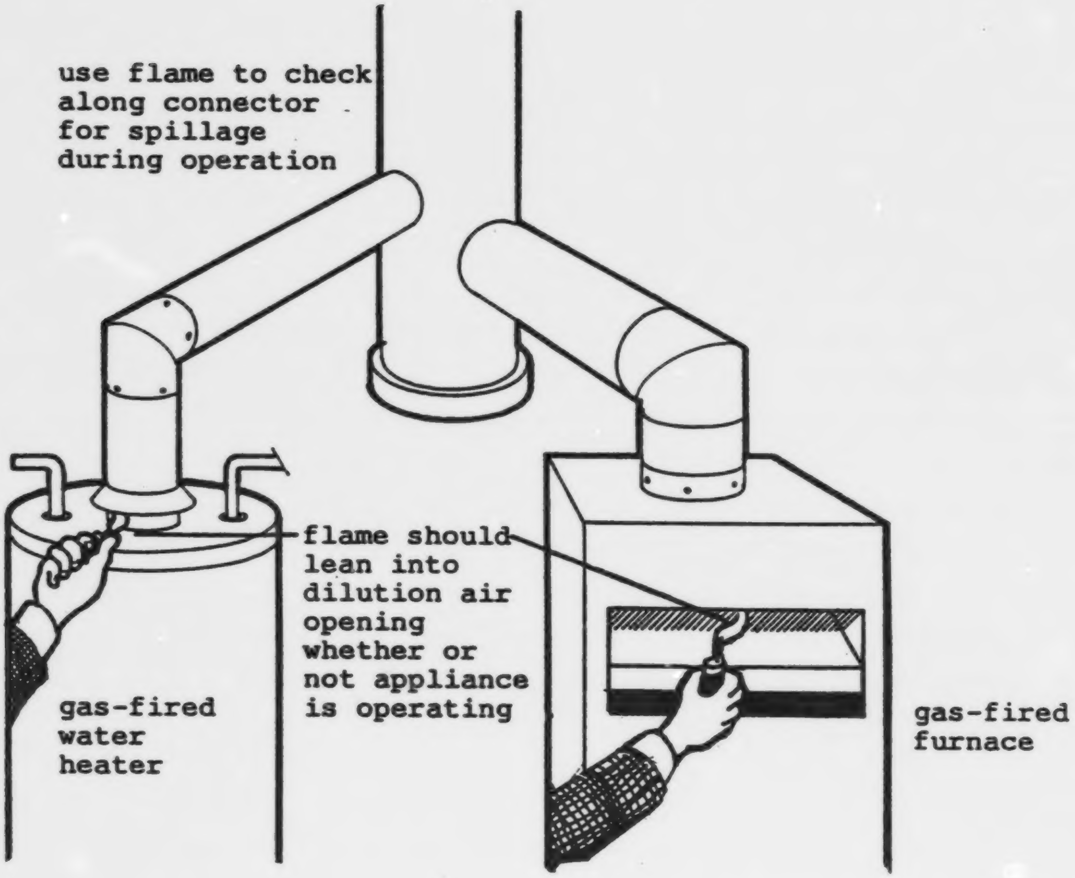
Turn the thermostats on the furnace and hot water heater down as far as possible. You want to ensure they do not operate during the test.

Allow the chimneys to cool down to "stand-by" temperatures. Allow 15 minutes of OFF time for metal chimneys, and at least 30 minutes for masonry chimneys. Take advantage of this cool-down time to prepare the rest of the house.

Locate any exhaust fans inside the house that are ducted outside the house, or into attic or crawl spaces. If possible clean or remove any filters, grills or screens that cover these fans. Some typical exhaust fans are listed below:

TYPICAL EXHAUST FANS	COVERS TO CLEAN OR REMOVE
Kitchen Fan	Grille
Range Hood or Barbecues	Grease filter
Clothes Dryer	Lint Screen
Bathroom Fan	Decorative cover
Whole House Vacuum	Filter and/or bag
Whole House Fan	Louvered cover plate
Workroom fan	Grille or screen

Figure 4


use flame to check along connector for spillage during operation
flame should lean into dilution air opening whether or not appliance is operating
gas-fired water heater
gas-fired furnace

CHECKING CHIMNEY DRAFT WITH A FLAME FROM A BUTANE LIGHTER

Removing covers or screens is not essential. The intention is to increase air flow to add a measure of safety to the test results. Loosening or partly opening covers, or just cleaning the fan, is okay in cases where removal is inconvenient.

Fireplaces should be prepared for a rapid, hot fire. 'Fireplaces' include wood stoves if they have leaky doors, or if they are designed to operate like an open fireplace on occasion -- with doors open for periods of several minutes or more. (Do not bother to prepare and test any wood heaters that are truly airtight.)

Load the fireplace or woodstove with crumpled newspaper and kindling. Keep matches or lighter handy, but do not light the fire at this time. Close any chimney dampers, air inlet dampers, and glass or metal doors.

Close all exterior doors and windows as tightly as possible. All interior doors should also be closed, except in cases where the interior door separates an exhaust fan from the furnace room. (For example, the door to the furnace room would be left open, as would the door to a bathroom that contains an exhaust fan. Doors to bedrooms are typically closed.)

Practice checking the draft in the furnace chimney. The easiest way to check drafts is to use a butane cigarette lighter. These lighters cost less than $2 and are commonly available. An alternative to the lighter would be to use a candle and lots of matches.

The flame of the lighter is used to check the direction of chimney draft. Do this by running the tip of the flame along the upper lip of the dilution air inlet of the furnace. In the case of hot water heaters, the flame is held next to the draft hood.

When a proper upward draft is occurring in the chimney, as should be the case at the moment, the flame will lick into the dilution air opening, indicating that the flow of air is into and up the chimney. Practice holding the flame in the proper location and watching the flame characteristics. When backdrafting or spillage is occurring in a furnace or water heater, the flame will lean away from the opening -- sometimes violently -- and may be extinguished.

STEP 4 OPERATE EXHAUST FANS AND CHECK CHIMNEY DRAFT.

Turn on all exhaust fans in the house. Set multi-speed fans to the highest speed. Timed switches, such as often occur in bathrooms, should be taped ON to ensure that they do not shut off before the test completion. All exhaust systems should be operated simultaneously.

Return to the furnace (and water heater) and use your flame to check the draft at the dilution air inlets. If backdraft or spillage is now evident, your house has failed the test, and you must consult the last section titled, "Where to go from Here?" Otherwise, leave all the exhaust systems operating, and proceed to Step 5.

STEP 4: Additional instructions only for houses with continuous two-way ventilation systems such as "Air to Air Heat Exchangers"

Any heat recovery ventilation system should be left on at its continuous SLOW speed. If, however, the system is designed to operate on occasion as an exhaust fan only, then it should operated in HIGH speed as an exhaust system only. Such systems typically shut off the intake fan as a means of defrosting the system in cold weather. Check your appliance manual or call your installer if this is unclear. Normally it is relatively easy to cause a heat exchanger to operate in defrost mode. You can simply raise the temperature setting on the thermostatic control mounted on the unit, and then reset the control after the test is completed.

STEP 5 OPERATE THE FURNACE BLOWER AND CHECK AGAIN.

You should now manually operate your furnace blower.

Not all furnaces are provided with a manual switch for operation of the furnace blower. However, most furnaces will have a switch in one of two locations:

- at the front outside edge of the furnace casing, (close to where the wiring from the thermostat enters the furnace);

or

- on the fan limit control box inside the front cover of the furnace. (lift off the front cover of the furnace.)

Two-speed furnace blowers can be left operating at their continuous slow speed.

If the blower cannot be switched on by hand, skip this step and go on to Step 6.

Once again use the lighter flame to check for backdraft or spillage at the dilution air inlet of the furnace and at the draft hood of the water heater.

If spillage is apparent, consult the appropriate section in Where to go from Here. Otherwise move on to STEP 6.

(Houses with heat recovery ventilation systems - that is a system containing intake and exhaust fans - should operate the system at high speed for this test.)

STEP 6 LIGHT A FAST FIRE AND CHECK ALL THE CHIMNEYS.

(If you have no fireplace, move on to Step 7.)

Open interior doors into rooms containing a fireplace. If you have two fireplaces, begin by testing only the smaller fireplace. Later you can repeat the test for both fireplaces.

Before lighting the fire, temporarily open a nearby door or window to provide plenty of fresh air.

Open any doors on the fireplace itself.
Open the chimney damper in the fireplace.
Open any air supply inlets designed to feed air to the fireplace from outdoors.

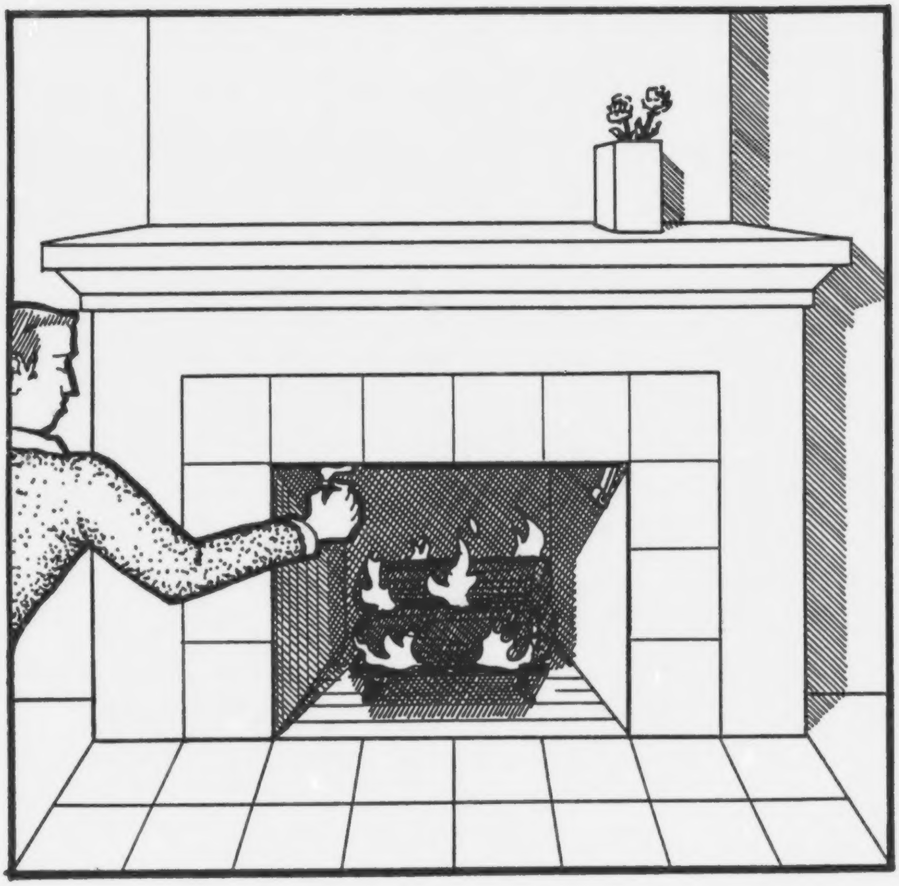
Turn on any air supply fans that are intended to force air into the fireplace room or fireplace opening.
Light the newspaper, and wait until the fire becomes a roaring blaze.

Now check for spillage along the upper edge of the fireplace opening. Use your flame (eg. butane lighter) and watch to see that the flame tip constantly moves into the fireplace opening as it is sucked with indoor air up the chimney. If there are signs of backdraft and spillage from the fireplace opening, consult the "Where to go from Here?" section.

Shut the door or window to the outside, and check once again for spillage from the fireplace opening. Use the lighter flame. If no spillage is evident move on to the next check-off. If spillage does occur, however, you'll need to refer immediately to Guideline 6 in the "Where to go from Here?" section.

With the fireplace blazing, and all the exhaust fans in the house still operating, return once again to the furnace and water heater. Use your flame to check for signs of backdraft or spillage at the dilution air inlet and at the draft hood.

Figure 5



flame should lean into fireplace opening along upper edge

CHECKING FOR SPILLAGE OF COMBUSTION OUT OF A FIREPLACE

If spillage is apparent, once again consult the Where to go from Here? section. Otherwise, leave all the exhaust systems and fireplaces operating. Proceed to Step 7 if you have no other fireplaces. In a house with two operational fireplaces, repeat Step 6 for the second fireplace.

STEP 7 OPERATE THE GAS FURNACE AND CHECK FOR SPILLAGE OR A POOR FLAME.

Operate the furnace and use the lighter flame to once again check for signs of spillage. To operate the furnace, simply untape and turn up the household thermostat. Since this prevents you from immediately checking for spillage from the furnace, it might be helpful if someone else could adjust the thermostat while you wait for the furnace.

Stand aside until after ignition, to avoid any hot back-puffing. Once the furnace begins to operate, hold the flame along the upper edge of the dilution air inlet, and check for signs of spillage. A small amount of spillage at start-up is fairly common. If spillage continues for more than about 15 seconds, however, the situation is not normal, and you should consult the "Where to go from Here?" section. If no spillage is evident at the dilution air inlet opening, check at other locations along the flue connector for signs of spillage. Hold the flame near any joins in the flue connector.

Use the flame to check for spillage at the water heater draft hood, (with the furnace still operating).

Finally, use your flame to check for spillage at the place where the flue connector joins the vertical chimney of your house.

If spillage occurs at any of these locations, your house has failed the test, and you should consult the "Where to go from Here?" section. Otherwise, leave the furnace operating and proceed to Step 8.

STEP 8 OPERATE THE GAS HOT WATER HEATER AND CHECK AGAIN FOR SPILLAGE.

Continue with Step 8 only if there was no indication of spillage around the draft hood of the water heater in Step 7. Leave all systems operating: fans, fireplaces, and furnace.

Operate the gas fired water heater by turning on the closest hot water tap and waiting a minute.

Once the water heater begins to operate, use your flame to check for spillage around the draft hood. Once again, check for spillage all along the flue connector. If spillage is apparent, the house has failed the Test, and you should consult the "Where to go from Here?" section.

If no spillage is apparent, the chimney is probably well designed and free of blockage problems at present. You can proceed to Step 9.

STEP 9 CHECK THE FIREPLACE FOR SPILLAGE AS IT DIES DOWN.

If your house lacks a fireplace, move on to Step 10. Otherwise, you should check the fireplace for spillage as it dies down.

Leave all household systems operating, including exhaust fans, furnace, DHW, and fireplaces. (It's okay if either the furnace or the DHW cycle on and off periodically.)

Return to the operating fireplace and close any fireplace doors. Use your flame to check for spillage around cracks in the doors. If there are no doors, check around the upper edge of the fireplace opening.

You should check periodically, as the fire dies down, to see if spillage begins while the fire is still warm. Remain by the fireplace, checking for spillage occasionally, until the fire is no longer generating significant amounts of heat. A small amount of spillage may be inevitable. Wood smoke always contains unhealthy substances. The degree of health risk will vary with the quantity of spillage. If spillage is occurring along the entire upper lip of the fireplace opening, you may have reason for concern.

If you find that an unacceptable amount of spillage is occurring while your fireplace is still warm and burning, you can open a nearby window until the spillage disappears. The size of window opening that succeeds in eliminating spillage, at this time, is the size of opening you should always have available when operating the fireplace, to ensure the health and safety of the occupants of the home.

If significant spillage was apparent as the fire died down, the house has failed the Test, and you should refer to the "Where to go from Here?" section. Otherwise, move on to Step 10.

STEP 10 RETURN THE HOUSE TO NORMAL OPERATING CONDITIONS.

Reset the house thermostat.

Turn off the hot water.

Turn off all exhaust fans except those needed at the moment.

Open or close the doors and windows in your home as appropriate.

WHERE TO GO FROM HERE?

This section is for anyone who has difficulty performing the Safety Test, or for householders who have discovered chimney spillage or backdrafting problems.

Sources of Expertise:

Further information and assistance in interpreting the results of the Chimney Safety Test can be obtained form a number of sources:

- The customer service department of your gas utility may be prepared to offer advice. Service personnel sometimes conduct inspections, especially in cases where householders have already experienced problems with a gas furnace or water heater.

- If you already have a regular maintenance contract with a certified and licensed gas fitter, you may wish to consult with this person regarding improvements to the combustion venting systems in your home.

- The provincial gas regulatory authorities can be of assistance, especially if the problem might be related to a faulty appliance or unsafe installation.

- A number of private consulting firms and contractors across Canada have experience in completing a more comprehensive version of the Chimney Safety Test. A list of these companies can be obtained from the Canada Mortgage and Housing Corporation [CMHC], although the availability, costs, and quality of such services are not regulated. A test by a professional may be warranted for houses that fail the test repeatedly, or for houses with unique features that make testing difficult.

A Review of Remedial Options for Problem Chimneys:

In many cases it is possible to eliminate backdraft or spillage problem by modifying the ventilation systems in your house, or the way you operate them. Some guidelines for avoiding failures in houses are presented below. The information is organized according to the Steps of the Safety Test. If your house failed the test at any Step from 4 to 9, refer to the appropriately numbered Guideline.

GUIDELINE FOUR: FOR HOUSES WITH CHIMNEY FAILURE IN STEP 4
(Exhaust Fan Operation)

A failure will most often occur in Step 4 due to the effect of an exceptionally powerful exhaust fan, such as a indoor stovetop barbecue. The exhaust capacity of fans can vary a great deal, depending on the type, size, age, and installation. The most powerful exhaust fans in a house are usually the stove top barbecue fans. Range hood fans can also be powerful, especially hoods with exterior mounted motors, or with large duct diameters, of 200 mm or more, or large rectangular ducts (75 x 250 mm). Clothes dryers are the next in line, especially those with 125 or 150 mm diameter ducting. Ceiling exhaust fans and Bathroom exhausts are not usually a major problem on their own.

If you suspect that the backdraft is occurring because of a single high powered exhaust, the easiest solution may be not to operate the fan without opening a nearby window for make-up air supply. If you choose to follow this route, you should label that exhaust fan accordingly. A suggested wording for the label is provided below:

CAUTION: AVOID CHIMNEY FAILURE! DO NOT OPERATE THIS FAN
WITHOUT OPENING A WINDOW TO SUPPLY MAKE-UP AIR.

Once you have completed a label for the exhaust fan, try opening the window as recommended, and then repeat the Chimney Safety Test to ensure that the house is now safe.

If the house has failed Step 4 and there is no single powerful exhaust fan, but rather a number of exhaust fans which, together, create a ventilation system imbalance, a better solution may be to provide additional fresh air supply to the furnace room. A 150mm (6") diameter duct into the furnace room, from outside, is probably a minimum. Ducts are most likely to solve problems in houses that a fairly tight to begin with.

Heating and plumbing contractors are usually familiar with techniques for installing air supply ducts. (It may even be possible for tradesman to install an automatic air supply duct that only opens when the fan or furnace is operating.)

After installing additional air supply to your house, you will want to ensure that chimney failure is no longer a potential hazard. If the additional air supply has succeeded in preventing chimney backdrafting, it's a good idea to place a cautionary label on the new air inlet(s). Appropriate wording for a label is provided below:

CAUTION: AVOID CHIMNEY FAILURE. DO NOT BLOCK OR RESTRICT
THESE OPENINGS. OUTSIDE AIR IS ESSENTIAL FOR SAFE
OPERATION OF CHIMNEYS IN THIS HOUSE.

Opening windows or installing air supply ducts are not the only options for avoiding backdrafting due to exhaust fans. Other possibilities include:

* installing alarms or warning devices on the furnace and water heater, to prevent backdrafting conditions from occurring without your knowledge; interlocking fans with the furnace, to avoid simultaneous operation;

* disabling fans during the heating season;

* ducting make-up air directly to the clothes dryer;

Contact a heating and ventilation specialist for more information on what can be done.

GUIDELINE FIVE: FOR HOUSES WITH A FAILURE IN STEP 5
(Blower Operation)

Spillage or backdrafting from a chimney during Step 5 can be a result of two completely different phenomenon. The first possibility is a very leaky heat exchanger inside the furnace. In short, the blower forces air through leaks in the heat exchanger, into the combustion chamber, pressurizing the furnace to a point where spillage occurs. It's easy to determine if the heat exchanger is at fault; simply open a nearby door or window to the outside and recheck for spillage. If the spillage continues, the problem is definitely a result of a leak in the heat exchanger of the furnace, and the most cost effective solution is likely to be replacement of the furnace itself.

The other reason why spillage and backdrafting might occur, during Step 5, is an imbalance in the air distribution system of the house. A furnace blower is a very powerful fan, which can drastically lower the air pressures around the furnace, if either:

- the furnace is sucking far more air than it should from areas directly adjacent to the furnace itself; or
- the warm air supply side of the duct work in the home is exhausting large quantities of air outside the house.

In either case, the effect is to convert the furnace blower into another exhaust fan.

Balancing of an air distribution system is a job that is usually best left to a heating and ventilating expert. It will be necessary to undertake a survey of the air distribution system prior to prescribing the most appropriate remedial measure. Some of the more common faults, with air distribution systems, are briefly listed below:

- a leaky or a loose blower compartment door, that permits large quantities of air to be sucked from the furnace room;

- leaky plenum joins, or leaky filter slots, that allow large quantities of air to be sucked from the furnace room;

- warm air supply ducts blowing air into areas that are not well connected to those parts of the house with return air supply ducts, (such as airtight bedrooms, new additions, heated garages, heated crawl spaces); or

- warm air supply ductwork, that is leaky. As it passes through interfloor areas, attics, and crawl spaces, it loses considerable air to the outdoors.

Solutions to these problems often include: the sealing of duct work with aluminum tape; sealing of furnaces and blower compartment doors with silicone caulking or weatherstripping; balancing of distribution systems through installation of additional cold air returns; installation of a fresh air intake duct connected to the return air plenum; or cutting an additional warm air register, to blow into the furnace room area. You'll probably need advice from an expert to choose the best strategy.

GUIDELINE SIX: FOR HOUSES FAILING STEP 6:
(Fireplace Problems and Furnace Backdrafting)

Three different types of problem situations may be encountered while conducting Test 6 of the Safety Test. Each is described separately below.

1. Fireplace spills even with window open.

Because a window (or door) is open to the outdoors, your fireplace spillage problem is not caused by competing exhaust systems (eg. exhaust fans). A variety of problems may exist with the fireplace itself. These include:

* constrictions in the chimney opening, due to excessive creosote build-up;

* blockage from a plugged spark screen, or from broken chimney lining;

* low draft in the chimney, due to excessive leakage from openings around the base of the fireplace, or through cracks and holes in the masonry; and

* a poor fireplace design, wherein spillage occurs through an opening that is too large, or because of a flue diameter which is too small.

A fireplace expert should be consulted if the problem is not obvious. Remember, though, that diagnosing poor draft problems in a fireplace can be difficult, even for an expert.

2. Fire begins to spill after window has been shut.

It is not uncommon for fireplaces to spill once the window (or door) is shut. Back pressures, caused by exhaust fan operation, will weaken the fireplace chimney draft, reducing its capacity to remove the hot, smoky gases. Because a roaring fire produces so much hot air and smoke, the result may be spillage around the fireplace opening.

If the fireplace is equipped with doors, the solution may be to close the doors. Because most fireplace doors are designed to be leaky, however, the doors are unlikely to have enough effect. Nevertheless, try closing any fireplace doors and checking again for spillage.

If spillage persists, the best solution is probably to lower the back pressure, by providing more make-up air to the house. Once again, partially open a window or door to the outside, but just a little at a time. Keep opening in small increments and rechecking the spillage, until the opening is sufficient to eliminate all spillage from the fireplace opening. Note the size of this relief opening. This size of air inlet will always be required when your fireplace is operating at full burn. You might want to label your fireplace as follows:

CAUTION: AVOID CHIMNEY FAILURE
PROVIDE ADDITIONAL AIR SUPPLY FROM OUTDOORS WHILE OPERATING THIS FIREPLACE. AIR SUPPLY OPENINGS SHOULD BE LEFT OPEN UNTIL THE FIRE COLD.

3. Furnace spills or backdrafts during fireplace operation:

A roaring fireplace will commonly cause backdrafting in a cold furnace chimney. You must consider the operation of the fireplace unsafe until additional air supply has been installed. The easiest solution may be to simply block off the fireplace and avoid use. Or consider an airtight wood stove or fireplace insert. If air supply is to be installed, the easiest (but not the best) solution is to open a nearby window, or install a duct and damper through the wall or floor to the outdoors. The best location for air supply is directly inside the fireplace opening. In combination with fireplace doors, a direct air supply duct will ensure the fire burns efficiently, without lowering pressures in the rest of the house, or freezing the room. Various kits exist for this purpose and are sold through fireplace stores. The ash clean-out in the fireplace can be used as air supply route, if properly retrofitted. However, the best location for supplying air to a fireplace is at the floor level, between the fireplace doors and the fire.

A large quantity of air may be required to feed a roaring fire. To find out just how much relief area is required for your fireplace, you can repeat the

Safety Test with a nearby window opened by varying amounts. The size of window opening sufficient to prevent spillage at the furnace, during fireplace operation, is an indication of what is required. Of course, the area of a permanent inlet will have to be larger than the relief area you measured around the window or door, because outlets, screens, and louvres restrict air flow through an opening. The inlet area should be doubled to ensure a similar air supply. On the other hand, the inlet area may be reduced, if fireplace doors are installed at the same time. The best solution is to install airtight doors, and provide 100% of the fireplace air through the outdoor air supply duct. This is an expensive proposition, however.

GUIDELINE SEVEN AND EIGHT: FOR HOUSEHOLDERS ENCOUNTERING SPILLAGE FROM AN OPERATING GAS FURNACE OR HOT WATER HEATER

When encountering spillage during Step 7 OR 8, the first action should be to determine whether the spillage is a result of low indoor house pressure or a deficient chimney. To determine if low indoor pressure is the problem, open a nearby window and check again for the spillage. If opening the window eliminates spillage, repeat Step 7 from the start, to ensure that spillage does not continue for more than 15 seconds. If the repeat check shows the problem has been eliminated, the long-term solution will be to install additional air supply into the furnace room, or other measures to remove the imbalance in the ventilation system. Contact a contractor specializing in heating and ventilating systems.

If spillage continues, even after opening a nearby door or window to the outdoors, the chimney is somehow deficient and you need to consult with a chimney expert immediately. A deficient chimney is not a common occurrence. The problem might be:

- a chimney blocked by a broken peice of tile lining, a bird's nest, or a dirty cap;

- a poorly designed chimney, with too long or low a slope, or too many turns or connections;

- a chimney that is leaky or broken, or poorly connected; or

- a chimney that is too small for the appliances to which it is connected.

In any case, a chimney expert should be consulted.

GUIDELINE NINE: FOR HOUSES WITH A FIREPLACE THAT SPILLS AS IT DIES DOWN:

Spillage from a fire that is dying down is a fairly common occurrence, although the health hazard should not be underestimated. Even the embers of a dying fire can generate large amounts of poisonous gases (carbon monoxide), or cancer causing substances (benzo-a-pyrene).

Preventing spillage from a dying fire can be a difficult task. A common approach is to install fireplace doors, plus a fresh air inlet into the fireplace. This approach is expensive, and does not necessarily avoid spillage problems. Doors for fireplace openings are usually designed to be leaky, so they won't suffer from overheating. This makes it easy for spillage to occur, in low burn conditions, since the fireplace smoke will leak back through the doors, into the room, often in considerable quantities. Because the doors are so leaky, they do not help to isolate the fireplace from the rest of the house - the air supply in the fireplace opening simply provides make-up air to other exhaust systems in the home. In other words, fresh air from the fireplace inlet can be drawn over the dying fire, then through the fireplace doors, to provide make-up air supply for operating exhaust systems or other heating systems in the house.

If you choose the option of providing a direct air supply duct to the fireplace opening, as well as fitting the fireplace with doors, you'll need to repeat Step 9, to assess whether any remaining spillage is acceptable. Other options for coping with spilling fireplaces include:

- installing truly airtight doors, made of ceramic-like glass and heavier gauge metal;
- an airtight wood stove insert for the fireplace;
- a carbon monoxide alarm mounted near the fireplace, to warn if excess levels of CO are spilling into the house;
- a smoke alarm, mounted on the mantle of the fireplace, to warn of any significant spillage occurrences.
- special air supply to the exhaust fans and furnace in the house, to be used whenever fireplaces are operating; or
- an open window in the fireplace room, that can be left open until the fireplace is completely cold.

RESIDENTIAL COMBUSTION SAFETY CHECKLISTS

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APPENDIX III

COMBUSTION VENTILATION HAZARDS IN HOUSING:

Failure Mechanisms and Identification Technologies

Prepared for:

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

by:

Sheltair Scientific Ltd.

March, 1985

PREFACE

Combustion Venting Hazards in Housing is a background document summarizing research undertaken as part of the design of the Combustion Safety Check.

This Appendix discusses, in general terms, the entire range of combustion ventilation problems that might be encountered in a home. Types of failures have been classified, and some of the specific contributing factors are described, at least so far as the current knowledge will permit.

Also included is: a discussion on the relative frequency and severity of each venting hazard; an outline and evaluation of the different procedures that can be used for identifying any particular problem; and, finally, a description of the most appropriate remedial measures to be considered for each potential failure.

The broad scope of this document does not permit a detailed technical description of the failures encountered during the field research on the Safety Check and Backdraft Checklists. Nevertheless, this Appendix can serve as a reference for persons involved in revising or improving the Safety Check design, or for users of the Safety Check who might wish to better understand its purpose and rationale. It can also serve as a basis for preparation of training materials on the Safety Check.

Two additional chapters were planned for this Appendix; one on Fireplace Spillage Hazards, plus another on Wind Downdrafting. A limited budget, and a scarcity of information, have prevented the inclusion of these chapters.

APPENDIX III

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1.0 CHIMNEY BACKDRAFTING IN FURNACE AND HOT WATER HEATERS

1.1 FAILURE MECHANISMS:

Chimney backdrafting refers to flow reversal in a chimney, wherein outdoor air rushes down the flue and the combustion gases from the furnace or water heater spill into the house, through the dilution air opening or other leakage areas. The chimneys can be caused to backdraft by low indoor air pressures that overcome the natural buoyancy of air in a chimney. When indoor pressures are low enough to overpower the natural chimney draft, the chimney backdrafts and functions as an air supply route into the house.

1.11 Oil-Fired Appliances

Oil furnaces typically lack any pilot light warming, and therefore can cool to ambient indoor temperature during off-cycles. The effect is to virtually eliminate updraft pressures, in oil furnace chimneys, on cool days. Because oil burners incorporate a squirrel-cage fan for combustion air supply, the chimney is provided with a degree of forced draft, if necessary.

An oil burner fan can create total pressures of 30 to 40 Pascals, within the first 15 seconds of operation. It is therefore possible for an oil furnace to quickly re-establish updraft after start-up, since downdraft pressures would rarely exceed these levels. The effect of downdraft is to create backpuffing, sooting, spillage, and odors - during the start-up period only.

1.12 Gas-Fired Appliances:

The backdrafting hazard is most acute in naturally-aspirated, gas-fired appliances. If a gas-fired furnace or water heater begins to operate, while the chimney is experiencing a cold backdraft, combustion gases will spill into the house, through the dilution air inlet opening. Typically, the hot gases are unable to pierce the cold column of backdrafting air. Because the chimney remains cold, the appliance/chimney system is incapable of establishing a proper updraft. The result can be a full-cycle operation with spillage of combustion gases indoors.

When a downdraft begins in a chimney, it has the effect of cooling the chimney, which further lowers the chimney updraft pressures. As the chimney cools, the downflow of outside air increases. In this way, a cold, backdrafting chimney can achieve a steady-state condition, and may continue to downdraft even in the absence of operating exhaust systems in the house. The stack pressures in the house alone, which tend to ensure a lower indoor pressure than outdoor pressure, in the areas of the basement where the furnace and DHW are often located, are sufficient to maintain a continuous backdraft, once the downflow has begun. This kind of situation can result in spillage on start-up, and possibly a continuing backdraft operating condition.

Gas appliances are often capable of re-establishing an updraft in the chimney, if the relative pressure difference between the furnace room and the out-of- doors is no more than about 2 Pa. As a furnace or water heater fires against a downdrafting flue, combustion gases spill into the furnace room, with subsequent warming of the room air. The appliance itself also gets hot, and conducts some of that heat to the flue connector. The velocity of the gases emerging from the heat exchanger can also contribute to flow reversal, depending upon the design characteristics of the flue connector and draft hood.

After an initial period of backdrafting and spillage, the chimney may eventually regain proper updraft.

Because chimney draft pressures usually exceed 2 Pascal, backdrafting does not often occur at such low pressures. For this reason, and because the cooling that takes place in the backdrafting chimney further increases the back pressures, a majority of gas furnaces and DHW will continue to backdraft for the duration of their operating cycle.

1.13 Ventilation Imbalances:

Low indoor air pressures are created in houses when there are insufficient openings for outdoor air to replace air exhausted by exhaust fans or fireplaces. Depressurization, sufficient to cause backdrafting in chimneys, can occur in houses that are tighter than average, or in houses where air supply requirements are higher than average, due to powerful or numerous exhaust systems. The problem is best defined as **an imbalance between air supply and air exhaust systems.**

The maximum depressurization that can occur in a house is experienced when the house is as tight as possible and also has all mechanical exhaust systems and fireplaces in full operation. Figure 1 shows the relationship between varying quantities of exhaust air capacity and total house depressurization, for a variety typical housing types. The total depressurization can be seen to increase as houses are tighter, or as the exhaust flow increases.

For houses as tight as the typical R2000 house, (500-700cm2), it is evident that even small quantities of exhaust flow can produce extremely high differences in indoor/outdoor pressure. The necessity for balanced ventilation systems, in this type of house, is obvious. For conventional construction in existing housing stock, the probable range of house depressurization will vary, on average, between 2 and 6 Pascals. This assumes an average exhaust capacity in the range of 100-200 L/s.

Of course, many houses will greatly exceed these average ELAs and exhaust capacities. (It is also worth noting that this range of pressure will only be experienced when the house is closed up tight, and all exhaust systems are operating simultaneously.) For many leaky existing houses, with ELAs in the 2000+ cm2 range, the depressurization from the combined exhaust systems is probably insignificant. On the other hand, many conventional "leaky" houses can experience inordinately high levels of depressurization if exhaust capacity is increased to 250 or more liters per second.

1.14 Chimney Draft Pressures:

Whether or not a backdraft occurs, as a result of house depressurization, depends on the total chimney updraft pressure. If the total chimney updraft is 5 Pascals, and the furnace room is depressurized by only 4 Pascals, the chimney will continue to function properly. If, for any reason, chimney pressures drop below 4 Pascals, backdrafting begins.

The total chimney updraft pressure is a combination of static pressure at the base and velocity pressure of air and gas moving up the flue. This total chimney pressure will increase with the height of the chimney, and with increasing temperature differences between the chimney and its environment. An estimate of chimney draft can be calculated using the equation outlined in Figure 2. This equation reduces to a rule of thumb of 0.05 Pascals per meter, per degree Celsius. Actual chimney pressures may vary slightly from this calculation, due to a number of factors including:

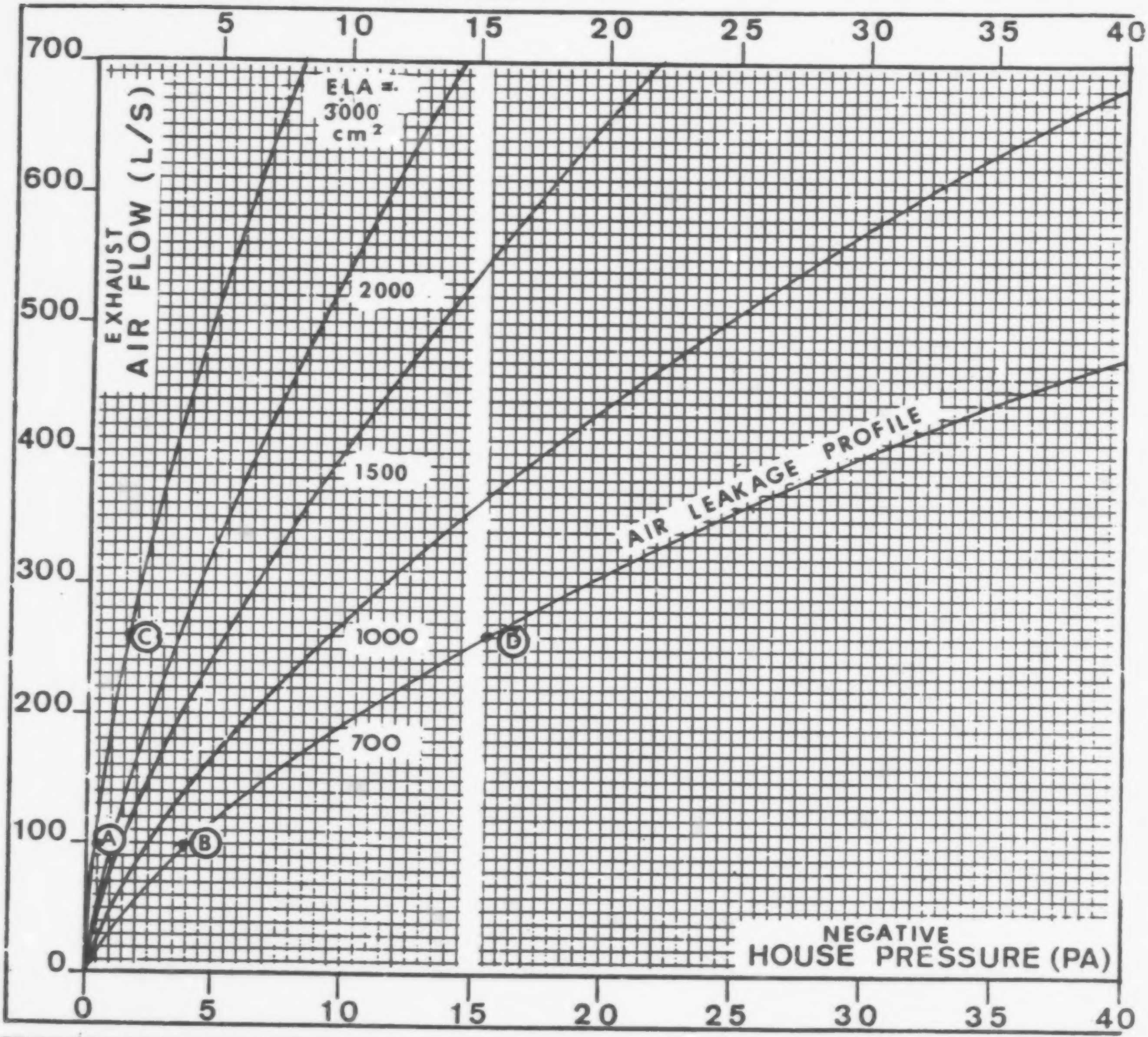
* the conductive heat transfer through the chimney wall, which reduces the buoyancy of the chimney gases as they rise through the flue;

* the natural back-pressure created by the stack forces in the house itself, which cancel a portion of the chimney draft, depending upon where the chimney base is located relative to the vertical centre of leakage area on the house envelope.

* wind movement across the top of the chimney, which typically creates a venturi effect, lowering the outdoor pressures above the chimney and increasing the total chimney updraft; and

* the variable effects of pilot lights on gas appliances, which contribute heat (and thus buoyancy) to the chimney.

FIGURE 1: SHOWING THE RELATIONSHIP BETWEEN EXHAUST AIR FLOWS AND DEPRESSURIZATION FOR HOUSES WITH VARYING DEGREES OF AIRTIGHTNESS



A NOTE OF EXPLANATION:
The typical combined exhaust flow for a house might equal 100 litres per second. (eg. dryer bath and range fans).
At 100 l/s house depressurization will vary from 0.5 Pascals for a "leaky" house (A), to 3.5 Pa for a "tight" house (B).
Add a fireplace or powerful kitchen fan to the exhaust flow and flows might increase to 260 l/s, producing a range of house depressurization from 1.5 Pa (C), to 15.5 Pa (D).

LEAKAGE CURVES FOR HOUSES

700 cm2	average R2000
1000 cm2	tight new house
1500 cm2	weatherized
2000 cm2	average Ontario
3000 cm2	leaky house

Pilot light operation, on a gas appliance, usually increases chimney gas temperature between 5 and 10 degrees Celsius, increasing buoyancy and thus helping to maintain updraft, even on warmer days.

Figure 3 presents the physical characteristics of a variety of chimney types across Canada, with the indoor/outdoor temperature data and total flue pressures. The data was collected during a 1984 research project by Sheltair Scientific, (ref.3). Flue pressures were measured with a static pressure gauge at the base of the chimney, (with the flue temporarily plugged so as to convert total pressure to static pressure). The furnace and chimney had been allowed to cool to ambient conditions, but with pilot lights left operating. The data indicates that typical updraft pressures in chimneys vary considerably from house to house, and as a result of changing weather conditions. Total pressures range from a low of 3 Pa. to a high of 23 Pa. With outdoor temperatures below freezing, it is usual for updraft pressures to exceed 6 Pa.

FIGURE 2: A SIMPLIFIED MODEL FOR ESTIMATING TOTAL FLUE DRAFT PRESSURES

$$\text{Total Updraft} = H * g * e * \frac{\triangle T}{273} = 0.045\ H \triangle T$$

Where: Flue Updraft = Pascals pressure drop from chimney base to chimney top

H = Height of Flue in meters
g = force of gravity (9.81 m/sec{2})
e = air density (1.29 Kg/m{3} at STP)
T = flue temperature - ambient temperature (K)
273 = heat energy in degrees Kelvin

FIGURE 3: CHIMNEY CHARACTERISTICS AND MEASURED FLUE PRESSURES FOR A VARIETY OF CANADIAN HOUSES

House ID	Maximum Flue Pressure (Pa)*	Temperatures		Electronic Ignition	Height of Chimney (M)	Diameter Of Flue (mm)	Furnace Make	Furnace Model	Output (KWH)	Fuel
		Furnace Room	Outdoor							
OTT 1	6.5	14.5	-20.0	Yes	6.5	160	Clare Bros.	MB6-120	28.0	Gas
OTT 2	7.5	13.0	-20.0	No	9.0	120	York Borg.	UGR-120	26.7	Gas
OTT 3	10.0	13.0	-14.0	No	9.0	125	York Borg.	P9U6007	11.7	Gas
OTT 4	5.5	18.0	-20.0	No	6.5	160	Clare	N/A	N/A	Gas
OTT 5	2.5	15.0	- 9.0	Yes	9.0	130	Metro Heat	L-1000SU	23.4	Gas
BC 1	3.0	16.0	9.0	No	N/A	100	Furnace Man	HG902W	21.1	Gas
BC 2	5.0	19.0	2.0	No	N/A	125	Lennox Crown	G12R013	26.6	Gas
BC 3	5.0	19.0	9.5	No	2.8	150	British Amer.	BA-L95	24.3	Oil
BC 4	5.0	20.0	4.0	No	5.5	125	Airco	AGH100	23.4	Gas
BC 5	7.0	20.0	7.0	Yes	6.0	125	Airco	AH90	21.1	Gas
PEI 1	17.0	18.0	- 7.0	Yes	4.5	125	Brook	LO-1M	32.8	Oil
PEI 2	7.0	20.0	- 2.0	Yes	8.3	150	Thermo Radiant	TB71-AX7	42.5	Oil
PEI 3	12.0	18.0	- 1.0	Yes	5.3	150	Thornes	KD113	33.1	Oil
PEI 4	6.0	21.0	-12.0	Yes	6.6	170	Freco	N/A	34.4	Oil
PEI 5	23.0	19.0	- 4.0	No	N/A	175	Summers	PACK-O-MATIC	34.4	Oil
TOR 1	8.0	19.0	- 8.0	No	4.8	101	Lennox	N/A	19.2	Gas
TOR 2	7.0	16.0	- 6.0	No	N/A	152	Lennox	GB-150	35.2	Gas
TOR 3	4.0	20.0	3.0	No	N/A	101	Lennox	GB-02-55-01	12.9	Gas
TOR 4	7.0	18.0	-16.0	No	N/A	114	Smarts	SHC-90.2	31.1	Gas

---

* Combined velocity and static pressure with appliance at stand-by.

REFERENCE: Sheltair Scientific Ltd., RESIDENTIAL CHIMNEY BACKDRAFT CHECKLIST: Design and Evaluation February 1984, Prepared for Canada Mortgage and Housing Corporation

As part of the 'design phase' research on the current study, a number of chimneys were monitored for pressures, under varying weather conditions, to determine the extent of pressure change with outdoor temperature.

1.2 FACTORS CONTRIBUTING TO CHIMNEY BACKDRAFTING

In general, the factors which contribute to chimney backdrafting are those which increase the exhaust capacity of a house, reduce the make-up air supply to the chimney, or contribute to low draft conditions in the chimney. Some specific situations which are most often implicated in backdraft incidents are briefly described below:

1.20 Open Fireplaces

An open fireplace, with a roaring blaze, can consume as much as 200-250 L/s of indoor air. If no special measures have been taken to provide make-up air for the fireplace, the effect will be significant depressurization, even in house of average construction. Because of the high exhaust air capacity of an open fireplace, a majority of backdraft incidents in housing will involve the operation of an open fireplace. The fireplace chimney, when hot, can reach total pressures in the range of 20 to 40 Pascals, and when competing with the furnace and DHW, will usually succeed in backing up the other chimneys.

Often the worst situation will be a fireplace located in a basement den, close to the furnace, where the make-up air supply for both appliances may be limited because of tight, below grade construction. The effect of the fireplace, on the furnace chimney, thus becomes worse as interior doorways are closed.

1.21 High Powered Kitchen Fans

A recent addition to many Canadian houses is the stove-top barbecue fan. These are a popular item in kitchen renovations and permit the grilling and barbecuing of foods indoors. Also popular are high powered range hoods and island fans. The exhaust fans on popular brand barbecues can have a rated capacity of 160 L/s (Jenn-air), or 230 L/s (Thermidor). Range hood fan capacity will vary greatly, from 50 L/s to a high of 310 L/s, depending on duct and fan size. Rarely, if ever, does installation of these fans include a compensatory air supply system, despite the extremely high exhaust capacity and potential for chimney backdrafting.

House depressurization, resulting from installation of high powered kitchen fans, is likely to exceed the impact of the often-blamed air sealing retrofits. For example, in a conventional home, with an exhaust capacity of 100 L/s and a leakage area of 1500 cm2, the 'worst-case' depressurization might be 1.3 Pascals. Increasing the exhaust by 160 L/s produces depressurization of 5.0 Pascals, as opposed to reducing the envelope leakage area (optimistically) by 50%, which produces only 3.5 Pascals.

1.22 Clothes Dryers in Furnace Rooms

Clothes dryers are often located next to the furnace in a tight furnace room. Operation of the dryer, with furnace room doors shut, can place excessive demands on any make-up air supply systems. Clothes dryers vary considerably in their exhaust capacity, but some units can exhaust as much as 120 L/s, (with lint screen clean).

1.23 Depressurization by the Furnace Blower

Furnace blowers are powerful fans that circulate air at a rate of 250-450 L/s. If an imbalance exists in the forced air system, the blower can depressurize the furnace room. Most furnaces tend to depressurize their own rooms slightly, despite the fact that a warm air register may exist on the furnace casing, or on the warm air plenum directly above the furnace. The cause is often the extra air leakage around the blower compartment door, filter slot, or joints in the return air plenum. Houses with tight furnace rooms can experience depressurization of the furnace room. (Ref.5).

Greater depressurization will occur if the forced air system in a house is imbalanced, because of warm air registers blowing into leaky portions of the house. A tight bedroom, with an open window and the partition door closed, allows the furnace blower to exhaust a large quantity of air outside the house, while return air is drawn centrally. More common are leaky ducts or warm air registers that exhaust into parking garages, crawl spaces, or wall and ceiling cavities. Two-speed furnace blowers exacerbate any imbalance by permitting depressurization during off-cycles, when chimney draft is weakest.

1.24 Blocked Air-Supply Ducts

The blocking of essential air-supply ducts can create a potentially hazardous situation, by reducing the air required for chimney operation. It is not unusual to find air-supply ducts intentionally blocked off by the occupants of a house, as a means of either conserving energy or eliminating uncomfortable infiltration. There is usually nothing to indicate that these ducts are an essential part of the furnace chimney system.

Unintentional blocking of inlet ducts is a frequent occurrence as well. Sometimes, renovations on the outside of a house will close in a duct opening (eg, stair enclosures, tool sheds, garages). Many householders are unaware that the ducts exist, and consequently, over time, the effectiveness of the ducts decreases, as the screens and louvres on the exterior become plugged with dirt, grass clippings, insects, or other objects. Snow banks can bury the inlet opening during the heating season.

1.25 Major Air Sealing of the Envelope

Comprehensive house tightening, by professional weatherizers, will effectively reduce the make-up air supply, by eliminating (on average) 30 to 50 percent of the envelope leakage area. A similar reduction can also be achieved by replacing leaky, single-glazed windows with sealed double-paned units; by refinishing the interior; or by re- insulating walls and attics with a dense insulation like cellulose. At present there is rarely -- if ever -- any attempt to determine if such major retrofits have eliminated essential make-up air supply routes and created a hazardous ventilation situation in a home.

1.26 Weak Chimney Design

Some types of chimneys are prone to low updraft pressures and therefore become susceptible to backdrafting hazards. Converted gas furnaces, that exhaust into large masonry chimneys or exterior walls, will have difficulty maintaining enough warmth to ensure an updraft. Single-storey chimneys are more susceptible, because of their low height. Leaky chimneys and poorly fitted flue connectors permit greater cooling and further reduce the total draft.

1.27 Electronic Ignition and Thermally Activated Flue Dampers

A common combination of technology, on the west coast of Canada, is electronic ignition on a gas furnace, combined with a thermally-activated flue damper. This type of furnace will be particularly susceptible to backdrafting, because the lack of a pilot light allows the flue to cool. Closure of the thermal damper leads to heavy spillage at start-up and, if a backdrafting is occurring, the damper tends to remain cool and closed throughout the entire operating cycle.

1.28 House Temperature Set-Backs

The practice of turning back the household thermostats, for fuel savings, can increase the potential for hazardous chimney backdrafting. Temperature set-backs reduce chimney draft, by lowering indoor temperatures. At the same time, the furnace is non-operational for extended periods of time, allowing the flue to cool to ambient conditions. Operation of a powerful exhaust system, such as a non-airtight wood stove or fireplace, after the temperature set-back period, is a scenario that can lead to chimney backdraft.

1.29 Summertime Operation of Water Heaters

An atmospherically vented gas heater is particularly susceptible to backdrafting during summertime operation, when little indoor/outdoor temperature difference exists, and therefore little chimney draft. The problem will be most acute in airtight houses, where operation of a single exhaust fan, such as a clothes dryer or range hood, can provoke a chimney backdraft. There is a growing tendency for new energy-efficient houses to remain closed up tight, even during summertime, as a way of increasing mechanical or passive air-conditioning, for security or noise reduction, or to allow for continuous operation of a controlled ventilation and filtration system.

1.3 RISK OF BACKDRAFTING FURNACES AND WATER HEATERS

The percentage of the housing stock in Canada, that would fail the Vent/pressure component of the Safety Check, is probably in the range of 2 to 10 percent, (120,000 to 600,000 houses). Current data is too limited for a more confident prediction. Only houses without chimneys, or houses that lack competing exhaust systems, can be automatically excluded. Field test data, from this and previous CMHC studies on susceptible housing stock, would suggest that over a third of houses, containing mechanical exhaust systems, experience pressures above the proposed MAD limits. A review of airtightness test data, and nominal exhaust flaws for household fans (Ref. 2) would also suggest that about 1/3 of houses, nationally, are sufficiently airtight to be considered susceptible to potential backdraft failures.

The incidence of backdraft failures in houses is limited to a much smaller number of houses, since the "worst-case" conditions may never occur. Backdrafting is most likely to take place in the warmer portions of the heating season, and in those houses where only one or two exhaust systems are capable of reversing flues. Some houses must be experiencing backdrafting on a day-to-day basis. For others, it's an event that coincides with occasional use of the fireplace. Summertime flow reversal of gas fired water heaters is probably the most common failure, and has been recognized and accepted as "normal" by many gas inspectors. Householders might think otherwise, if they were aware of the problem, but they're not.

The extent of health hazards, associated with chimney backdrafting, is little understood. Since backdrafting of gas-fired appliances is relatively common, the acute health risk cannot be severe. When CO is present in the flue gases, in concentrations higher than about 50 ppm, backdrafting could result in headaches, nausea, and other non-specific ailments. Concentrations higher than 400 ppm can be life-threatening. CO pollution is probably most common in cases where a furnace is already producing CO for other reasons.

The generation of CO as a result of backdrafting, is likely to occur only in very tight houses, where small quantities of exhaust can cause a flow reversal, and where the products of combustion are allowed to accumulate and be recycled through the burner. In a conventional house, with a forced air system, this phenomenon would not occur. Instead, the cold air, dropping out of the flue, would ensure a constant supply of fresh air directly to the burner. Hot gases, spilling from the dilution air inlet, would rise to the ceiling, where convection, and the forced air circulation system, would ensure good mixing with household air. The high exhaust conditions, which provoked the flow reversal, would usually contribute to further mixing and dilution of the combustion gases.

The carbon dioxide, water vapor, aldehydes, nitrogen oxides and other contaminants, that accumulate in a house experiencing an operating backdraft, will certainly contribute to a deterioration in air quality. Furnaces represent a greater risk than water heaters in this respect, because of greater output and operating time. Stale, damp air, condensation, mould growth, odors, and health complaints such as allergy, respiratory infections, stinging eyes and headaches, may result from the deteriorating air quality.

1.4 IDENTIFICATION OF BACKDRAFTING HAZARDS

Different approaches were evaluated for ease and accuracy in identifying backdraft potential in houses. A brief summary is provided below:

1.41 Visible Signs

On many of the houses experiencing regular backdrafting, the evidence was visible on the water heater tank, and sometimes on furnaces as well. Grommets around the water piping, adjacent to the draft hood, would be melted and/or burned, (see Photo). Paper tags would be charred. The surface of the tank or furnace, next to the spillage opening, would sometimes display evidence of staining and discoloration.

Other signs of regular backdrafting would be complaints of odors in rooms near the furnace, and heavy condensation on indoor window surfaces.

1.42 Performance Testing

Four performance tests have been evaluated, varying in sophistication. Each involves the creation of "worst-case" conditions, in which the house is made as tight as possible, and all exhaust systems operated simultaneously.

i) **Smoke or flame check of flue** - A smoke pencil, or flame from a butane lighter or candle, is held close to the flue opening, to check direction of air movement. If flow is out of the dilution air inlet, backdraft failure has occurred.

A further test, conducted only in the event of failure, entails operation of the appliance, to determine the time required for re-establishing updraft. Again, the direction of flow is tested by holding a smoke pencil, or flame, close to the flue opening.

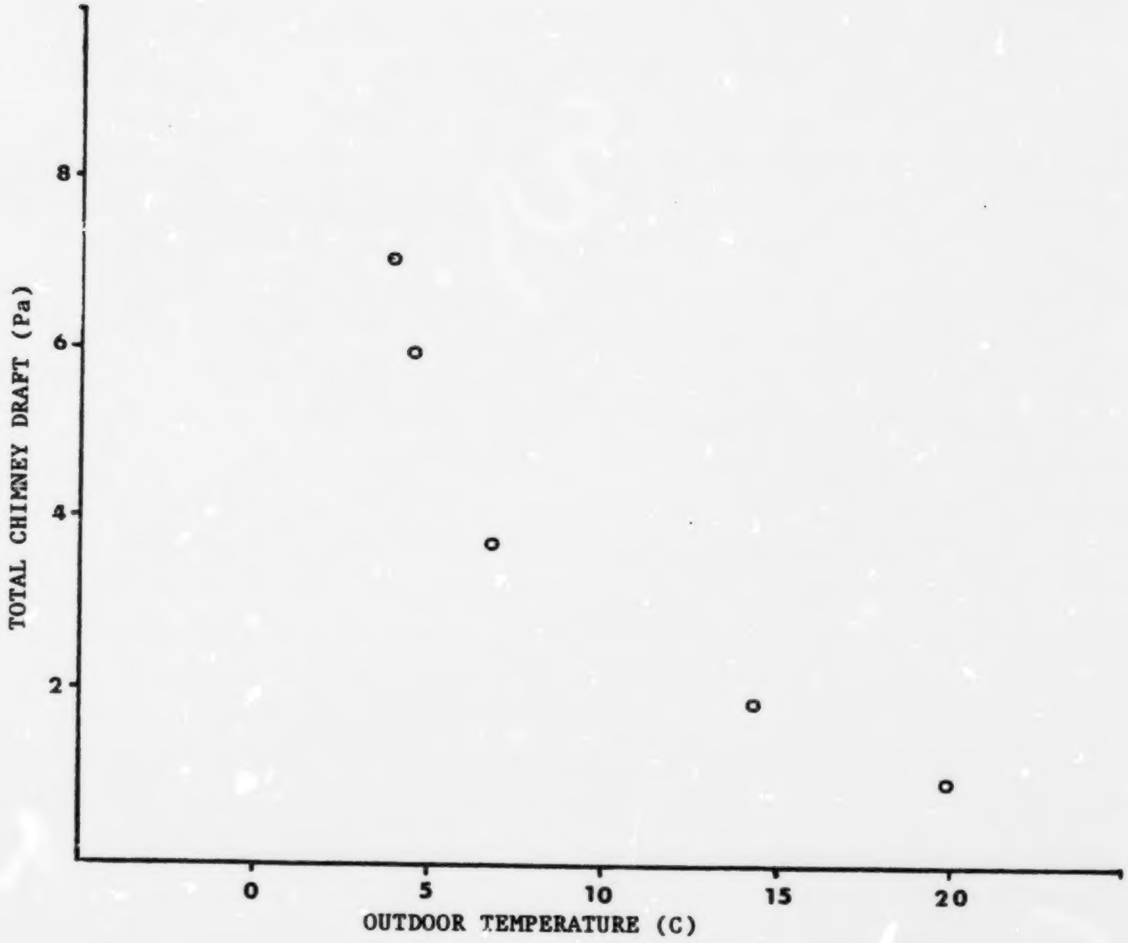
A smoke or flame check is difficult to conduct with accuracy, unless the day is warm, no wind is present, and the chimney has cooled to ambient. There is also no easy way to judge the of failure or success, although an approximation is possible by repeating the test with an open window (in the event of failure), or by adding an extra exhaust (to gauge the safety margin).

ii) **Pressure gauge in base of flue** - If a flue is temporarily plugged, (with a balloon for example), a pressure gauge can be used to compare the total pressure - or updraft - at the base of the flue, with the furnace room pressure. If the net pressure in the flue is negative, under worst case conditions, the house passes. The amount of pressure difference is a measure of the safety margin for the test house.

This technique has the advantage of adjusting to the particular strength of the chimney system under test. Unfortunately, typical variations in wind and outdoor temperature confuse the pressure measurement and make the procedure impractical. A mathematical correction can be applied to the pressure reading (to factor out temperature variations), but the sensitivity of the test is lost.

iii) **A comparison of indoor/outdoor pressures to MAD limits** - The procedure adopted for the Safety Check uses a measurement of indoor-outdoor pressure differences to determine the maximum depressurization of the furnace room. This pressure difference is then

FIGURE 4 AN EXAMPLE OF CHIMNEY DRAFT VARYING WITH OUTDOOR TEMPERATURE



CASE DESCRIPTION:
Basement temperature constant at 18°C.
Wind calm.
Furnace off for at least 30 minutes prior to measurement.
Pilot light left operating on Olson gas furnace.
Chimney height of 6.5 metres.
A tile lined flue 275 mm X 162.5 mm.

compared to a nominal Maximum Allowable Depressurization (MAD) limit for the type of appliance and chimney under test. The advantage of the procedure is the improved accuracy, and the capability of testing under a normal range of weather conditions. (The use of horizontal pressure averaging tubes prevents distortion under windy test conditions, although winds higher than 15 kph would make testing difficult).

The test is also an easy way of evaluating potential remedial measures, since opening relief areas, or shutting off fans, will have a measurable impact on the gauge. A minor problem with the test is the necessity to plug the flue (or it becomes a possible inlet/exhaust device). More of a problem is the need for a large safety margin, to compensate for the loss in accuracy when using a nominal depressurization limit. For example, leakage in the flue connector may weaken chimney draft. If the inspection routine does not reveal such a defect, the nominal limit will be wrongly applied.

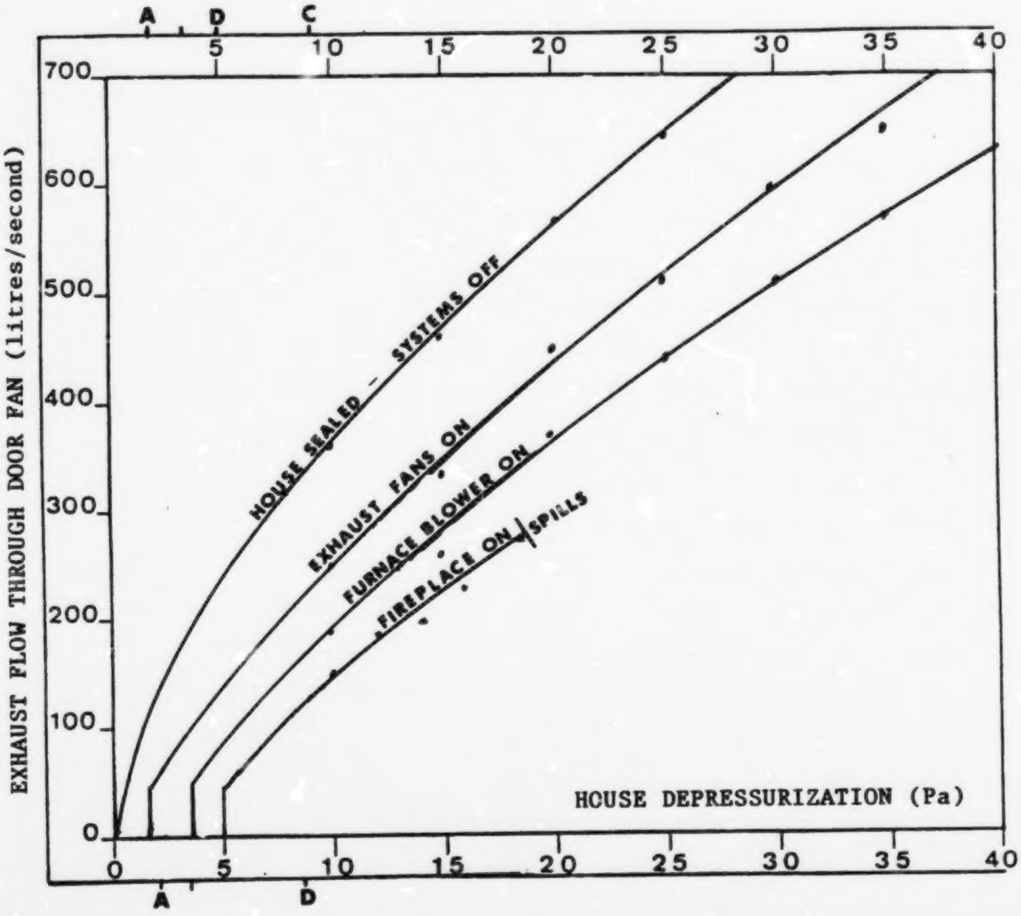
The MAD limits presented in this project report have been based upon the range of failure pressures identified in the 1984 Sheltair research on chimney backdrafting (Ref. 3). A sensitivity analysis of these limits has been proposed, using the parameters developed by Scanada Consultants (Ref. 6).

iv) **Door Fan Testing and Vent/Pressure Profiles** - The use of door fans (depressurization apparatus) in test houses has improved the accuracy and detail of backdraft evaluations. A procedure, developed during the Sheltair research of 1984 (Ref. 3), and repeated in the current study, involved the creation of Vent/Pressure Profiles - a graphic technique that summarizes all relevant data concerning exhaust systems and chimney failure pressures.

A Vent/Pressure Profile, for House 36 of the current study, is presented in Figure 5. The curves represent airtightness test results for the house under different operating conditions. The steepest curve is the flow/pressure relationship when the house is tightly sealed (similar to CGSB standard test, but with all flues and fans plugged). The same test is then repeated, but with an exhaust system operating. As additional exhaust systems are turned on, the test is repeated, and the result is a series of

FIGURE 5 A SAMPLE VENT/PRESSURE PROFILE:
Illustrating house pressures, exhaust flows, and chimney failure pressures for House #36

FURNACE FAILURE PRESSURES (Pa)



WATER HEATER FAILURE PRESSURES (Pa)
(A=cool backdraft B=operating spillage C=hot backdraft D=re-establishment)

TEST CONDITIONS:
Wind calm.
Outdoors 18.9 C.
Indoors 21.8 C.
Atmospheric 101 kpa.

FURNACE:
A down-flow, single speed, naturally aspirated, 60,000 BTU, ICG gas furnace.

lesser curves that reveal the impact of the exhaust systems on house pressures. The recorded air flow is for the door fan only. At any specific pressure, the difference between the lesser curve, and the steepest curve, is the exhaust flow supplied by the particular combustion of exhaust systems under operation. Each curve begins at a house pressure equivalent to the Indoor/Outdoor pressure recorded by the Safety Check procedure. The fireplace curve is a shorter curve, because it terminates at the pressure which causes smoke to spill from the fireplace.

By monitoring the furnace chimney during an airtightness test, using smoke pencil or flame, it is possible to determine the specific pressure at which backdraft occurs - both in a cold and in a hot chimney. It is also possible to record the maximum house depressurization at which a chimney is capable of re- establishing up-draft (within a reasonable time period). These critical failure pressures, for the chimneys, are labelled along the upper "X" axis of the Vent/Pressure Profile.

The Vent/Pressure Profile thus provides a record of how the exhaust systems in a house operate, alone and in combination, at varying house pressures. The safety margins are easy to calculate, for each system (not just in terms of pressure, but also in terms of air flow, and house leakage area). The ability of chimneys to successfully reverse a backdraft also provides a better assessment of the safety hazard. Prescribing the appropriate remedial measure is easier, because the relationship between exhaust flow, house pressure, chimney pressure, and leakage area is known. If the door fan is computerized, the exhaust flow capacities, safety margins and relief measures could be calculated automatically.

The problem with using a door fan is the added cost, complexity and time requirements. This approach is only practical in cases where a door fan is available for other reasons, such as leak location, standards testing, or ventilation retrofit.

1.43 Alarm Systems

Installation of an alarm next to a chimney, can identify a backdraft situation once it has occurred. Unlike performance tests, alarms do not provide an evaluation of backdraft **potential** (except in terms of frequency of occurrence). But, perhaps evaluations of backdraft potential are warranted only in cases where a hazard is known to exist.

The most simple alarm that could provide visible evidence that hot spillage had occurred would be a temperature sensitive material or apparatus, positioned next to the dilution air opening. Temperature sensitive dots, points or chalk can change consistency or color at specified temperatures. A wax rope, with a low melting point, might also work as a detection device. So would a min-max thermometer.

A more effective better alarm system is one that notifies the occupants of backdrafting, such as a thermodisc and buzzer system (described in detail in the Project Report). A conventional, battery-operated smoke alarm might work reasonably well for wood and oil-fired systems, if mounted close to the spillage location. (Smoke alarms were found to perform poorly when used as a detection device on gas-fired systems.)

A variety of commercial CO alarms exist, for use with gas and other systems. Most systems use a Figaro 812 or 813 CO sensor. The problems with this approach are the unreliability of the sensor, and the high detection threshold. Typically, an alarm is sounded when CO concentrations are 200 to 400 ppm. While this may be appropriate for wood fireplaces, the vast majority of backdrafting gas chimneys will never reach these levels, even if backdrafting is a regular occurrence. A CO_2 alarm might overcome this problem, but commercial units, for residential use are not yet economical. New technology for CO detection may soon be commercialized and may allow for low-watt, reliable sensors in the range of 20 to 50 ppm of CO. Such devices would provide excellent safety protection for all houses with chimneys, although they would still be unreliable as a device for warning of any significant gas spillage or chimney problems.

1.5 REMEDIAL MEASURES FOR BACKDRAFTING CHIMNEYS

The complexity of backdrafting failures, in conjunction with the many non-technical variables involved in choosing remedial measures, make it difficult to select a general strategy suitable for specific houses. Field evaluations have indicated that householders are likely to actively participate in problem solving, once options are identified.

A customized approach is therefore needed, in which a tradesperson can select one or more appropriate recipes from a "cook book" of possibilities. A standard fare is outlined below:

1.51 Increase the Chimney Draft

i) **Heighten the chimney:** (includes metal extensions, new masonry, boxed and insulated chimneys):

- cost is highly variable;
- difficult to find an agreeable contractor;
- cheapest and therefore most appropriate for gas vents, which can be extended with guy wires and pipe only;
- can add 0.5 Pa per meter during shoulder months;
- especially suitable for chimneys sheltered from cross winds, or suffering from wind downdrafts.

ii) **Straighten & tighten the flue pipe connector:**

- most appropriate for flues with convoluted design, or multiple connections;

- can be very cheap and effective;

- flue tape or silicone is suitable for sealing joins in the connector.

iii) Line the Flue:

- most appropriate for exterior masonry chimney used to vent a gas conversion furnace.

iv) Install a Delayed-Action Solenoid Valve:

- suitable for oil furnaces only;

- reduces sooting, backpuffing, odors, etc. for a cost of approx. $60 (material and labour);

- a good solution for marginal failures, where an additional air inlet is not desired by householders.

v) Install an Induced Draft Kit into flue connector:

- suitable for gas furnaces only;

- hot cost ($200-$300);

- spillage may still occur, and even backdrafting, if back pressures exceed 10 Pascals; - cannot be adapted to water heater, without major additional expense (+$200).

1.52 Additional Air Supply

i) Passive Inlet:

- suitable for marginal failures, in tighter houses with separate furnace rooms;
- comfort and cost problems for occupants;
- inappropriate for low draft appliances, since wind can have a major impact on operation at low pressures;
- design and installation issues are more important than most contractors will recognize (e.g. wind buffering, outlet location, insulation, mixing of incoming air).

ii) Passive Inlet with Mechanical Damper:

- suitable for gas or oil furnaces (if the damper can be approved);
- avoids problems of excess infiltration and cold drafts (price of approximately $150);
- damper can be wired in series with burner, or with exhaust fans, or both.

iii) Forced Air Supply:

- provides optimum quantity of air, on demand ($100-$200);
- suitable for balancing powerful exhaust systems; like range hoods or fireplaces;
- can also be used to improve air quality; - wiring can be costly

and troublesome; - needs proper maintenance and fail-safe circuitry; - can be too cold for comfort.

iv) Forced and Tempered Air Supply:

- the same as a Forced Air Supply, but overcomes problems of freezing air blasts;

- additional $30 for heater and thermodiscs; plus $35 for a thermistor and proportional controller (if desired).

v) Direct Air to Fireplaces:

- suitable for fireplaces with ash pit or other easy air supply route; should be combined with fireplace doors, or prefab insert.

vi) Direct Air Supply to the Clothes Dryer:

- suitable for house failing due to clothes dryer exhaust alone;

- may be possible to balance dryer system (within 20%)for a cost of $50.

1.53 Reduce Exhaust Capacity

i) Disable the Exhaust System:

- suitable for little used or unnecessary fans or fireplaces;

- a simple solution that may appeal to householder;

- suitable for houses with multiple exhaust systems;

- requires labelling of the fan or fireplace to avoid future use.

ii) Interlock fans and burner:

- 24V/110V relay switch prevents fan operation when burner is operating ($20 plus labour);
- suitable for powerful exhaust fans;
- wiring can be tricky in a finished basement, and costs will be higher;
- not suitable for gas-fired hot water heaters.

2.0 FURNACE HEAT EXCHANGER LEAKAGE:

2.1 FAILURE MECHANISMS:

The heat exchanger in a furnace is designed to transfer heat from combustion gases to circulating house air, while preventing any mixing of those combustion gases with indoor air. If a crack or hole exists in the heat exchanger, the potential exists for cross contamination, with the possibility of indoor air pollution. The contamination of indoor air can occur in four ways:

2.11 Exfiltration of Gases During Warm-up Period.

When the burner is operating, but the circulating blower is off, a slight positive pressure may exist in the upper portions of the combustion chamber, relative to the circulating plenum. Net positive pressures of approximately 1 Pa were measured during the field tests on a gas furnace. If leakage exists in the upper portion of the heat exchanger, (i.e., above the neutral pressure plane), combustion gases will slowly exfiltrate from the combustion chamber and contaminate the household air. This is probably the most common mechanism for contaminations of cracked heat exchangers. Unless the leakage area is large, however, the extent of contamination is likely to be small, because of the low pressure differential and the short duration of the warm-up period.

2.12 Scouring of Gases Through Leaks.

Because the furnace circulating blower is up-stream of the heat exchanger, the operation of the blower creates a relatively large positive air pressure, relative to the combustion chamber. Household air will thus enter the combustion chamber, if a leakage area exists. Field tests of pressure differentials were conducted (using a network of copper tubing to monitor pressures across the heat exchanger at various locations), during a range of operating conditions (see Photo). Pressures measured in the range of 40 to 75 Pascals, in all locations.

Venturi effects, around the downstream edge of the heat exchanger, did not significantly lower the pressure differential. However, a large amount of turbulence was apparent. Such turbulence might contribute to mixing of gases with circulating air, if a leakage area was sufficiently large, or irregular enough, to permit scouring of gases, by airflow in the circulating system.

2.13 Spillage of Gases out the Dilution Air Inlet.

Because leaks in the heat exchanger permit a flow of circulating air into the combustion chamber, the effect of a large leak will be to pressurize the combustion chamber, with the potential for spillage at the dilution air inlet. A leakage area of 9 cm2 (1.4 in2), for example, would force approximately 5 L/s into the combustion chamber during blower operation. On a 100,000 BTU gas furnace, 5 L/s represents a 20% increase in chimney flow requirements. Spillage thus appears likely, if the combined leakage area in a heat exchanger exceeds several square centimeters.

Field investigations of complaint houses, during research on the Residential Combustion Safety Check, revealed such a failure. A householder, complaining of a pilot light blowing out, was found to have a furnace with a leaking heat exchanger. CO2 tests indicated that at least half of the combustion gases were spilling from the dilution air inlet, due to pressurization of the combustion chamber.

2.14 Flame Distortions and Incomplete Combustion

The pressurization of a combustion chamber, due to cracks in the heat exchanger, can result in strong side or back currents, with subsequent distortion of the flame above the burner. Flame distortion can result in inefficient mixing of secondary combustion air, or in the cooling of the flame as it impacts on the walls of the heat exchanger. The effect of poor combustion may be to generate high levels of CO in the combustion gases - increasing the severity of any accompanying spillage problems. Over time, the poor combustion could generate soot deposits in the furnace and flue connector, increasing the possibility of blockage and spillage.

2.2 FACTORS CONTRIBUTING TO FAILURE OF HEAT EXCHANGERS IN FURNACES

A number of factors are known to contribute to the creation of leakage openings in a heat exchanger. The initial field research on failure mechanisms involved discussions with furnace manufacturers, senior service personnel, and research scientists, in addition to a literature review. Some of the factors, thought to most commonly be implicated in the failure of heat exchangers, have been briefly summarized below:

2.21 Thermal stress -- The most frequent reason cited for failure of heat exchangers is the thermal stress encountered by the heat exchanger, over long periods of operation. The typical gas furnace, of the highboy design, is thought to have a lifespan of 20-25 years. The actual lifespan of a heat exchanger is probably much shorter than 20-25 years, due to the often considerable time lag that exists between failure and discovery. The overall heat load on the exchanger is a contributing factor, but thermal stress is most related to cycling. Failure can occur anywhere between 3,000 and 14,000 cycles, depending upon the physical shape, material, thickness, and temperature distribution.

Failure often consists of long, ragged, hairline cracks forming around ridges, dimples, or other sharp bends in the hot zones of the heat exchanger (>500%F). The strain is greatest where movement of the metal is restricted and where the temperature changes are fast and extreme. A poorly maintained furnace blower will increase thermal stress, through inadequate cooling or slow start- ups.

2.22 Rusting -- Condensation (during operation of a gas furnace) is quite common, especially during the start-up period, and especially on units that are underfired. The deposit of moisture results in a slow corrosive process, which eventually causes failure of the heat exchanger as the metal is oxidized.

Rusting locations will be opposite to thermal stress locations, occurring in the coolest areas of the heat exchanger. The coolest locations will be those facing the air stream from the circulating blower.

Downflow and horizontal-style furnaces are thought to suffer more often from failure due to rusting, as their design makes possible a greater thermal range across the heat exchanger. The uppermost portion of the heat exchanger, in a downflow furnace for example, will experience the greatest cooling from circulating air, and the least amount of heating from the gas burner.

Rusting is likely to increase in areas where humidity is high. It has also been suggested that leaving furnaces over the summertime with the pilot off and no source of heat to keep the heat exchanger dry, can result in deposition of moisture on the heat exchanger, with subsequent rusting.

2.23 Corrosion -- Heat exchangers that are regularly exposed to ionic compounds may be quickly corroded. Owners of houses built on the shore of the ocean, for example, have been forced to regularly replace their furnace due to salt water spray corrosion. Furnaces installed in hair-dressing salons will reportedly last no longer than five years, due to the corrosive effect of halogens and chlorides used by the hair-dressers.

Furnaces installed in those furnace rooms that also contain washing and drying machines (that are used regularly) can also suffer from excess corrosion in the heat exchanger, due to the variety of chemicals (e.g. halogenated hydrocarbons) released into the air as aerosols from the clothes dryer, or as bleach and conditioners from the washing machine.

2.24 Failed gasketing -- Different varieties of gaskets are used to seal a heat exchanger to the furnace casing. If, over time, these gaskets deteriorate and fall apart, a seam may be left open, constituting a failure in the heat exchanger or carry-over vestibule.

2.25 Manufacturing flaws -- A variety of incidents have been recorded concerning furnaces that were installed in a faulty condition, which allowed leakage to occur across the heat exchanger. Flaws in the welding of the heat exchanger are possible. The omission of critical gasketing around the overflow vestibule is probably more frequent.

2.3 Frequency of Heat Exchanger Leakage

It is probable that a small amount of heat exchanger leakage is a common event, for many existing furnaces. Because the quantities of gases leaking through the exchanger are small, and because the direction of leakage is very often from the circulating plenum into the combustion chambers and up the chimney, the extent of existing failures does not necessarily indicate a health and safety risk for occupants.

The actual number of furnaces that are likely to suffer from cracks and leakage, during a typical lifespan of 20-25 years, is difficult to estimate. The techniques for identifying leakage are quite crude, and the symptoms of leakage are often undetected. Certainly, for a majority of furnaces, the existence of leakage will go undetected until the unit is replaced for other reasons. In the Vancouver, B.C. area, where service inspectors working for BC Hydro include 57 full-time inspectors responding to daily complaint calls, the number of furnaces red-tagged due to faulty heat exchangers amounts to about one in fifty furnaces visited, or a total of eight or nine condemned furnaces per day.

The Hatch report on Hazardous Heating and Ventilating Conditions in Housing, (Ref. 1), reported on 293 episodes of CO poisoning, including 145 deaths for the period form 1973-1983 in Canada. Equipment problems were implicated in 46% of the episodes. In 25 of these episodes, cracked, corroded or leaky heat exchangers were definitely described as a factor contributing to the poisoning incident.

The severity of indoor air contamination, resulting from leaky heat exchangers, is largely a function of the amount of CO produced by the furnace. In some cases, the effect of leakage will be distortion of the flame, with inefficient combustion. The inefficient combustion may generate large quantities of CO, which subsequently spill into the house. Alternately, the inefficient combustion can produce large quantities of sooting, which over a period of time, can effectively block the chimney or the heat exchanger opening, leading to back-puffing or spillage problems, and further deterioration.

2.4 Identification of Leaky Heat Exchangers

Techniques used to identify leakage in heat exchangers are, at present, extremely crude. The symptoms of a cracked heat exchanger are often undetected by the householder. Symptoms may amount only to a slight odour during start- up, or more possibly an increase in heating bills.

Perhaps the most common symptom of serious cracks will be the extinguishing of pilot lights on gas furnaces. Pilot lights are blown out when the circulating blower is operating and the burner has shut off at the tail end of the heating cycle of the furnace. It is often as a result of pilot lights being frequently blown out in this fashion, that a servicer will be alerted to leakage areas in or around the heat exchanger.

A variety of techniques have been employed for detecting the possibility of leakage through a heat exchanger. These techniques are briefly summarized and evaluated below:

2.41 Visual Inspection of Flame -- probably the most common method for evaluating the extent of the leakage in a gas furnace is by examination of the flame during full operation. A rolling or badly twisted flame, in any of the combustion ports in a furnace, may be an indication of air blown through leaks. This technique is highly subjective, and it will only identify major leaks, and then only those leaks that exist in the lowest portion of the heat exchanger.

It is not possible to use mirrors or other devices to inspect for leakage through the heat exchanger, since the flame is burning only in the lower portion and since there is no mirror which can withstand the heat of the flame without becoming tarnished. The narrow, uneven surfaces of the heat exchanger prevent a thorough visual inspection using a mirror without the flame.

2.42 Match Inspection -- A more effective technique for examining rate of leakage in the lower portion of the heat exchanger is to attach a flame, such as a wooden match, to an alligator clip on an extending pencil. It is then possible to move this flame around the walls of the heat exchanger from outside the furnace. If the blower is manually operated at this time, it becomes possible to detect leakage by watching for distortion of this flame as it is moved about the heat exchanger. Unfortunately, only the lowest portions of the exchanger can be easily inspected for leakage.

2.43 Injection of Odorant -- A technique often recommended in gas service training manuals is the use of a strong smelling oil, (e.g. oil of wintergreen) as a tracer gas in detecting leaks through the heat exchanger. The use of an odorant for this purpose makes use of the most sensitive equipment servicers are likely to be carrying on site -- their noses. A variety of different odorants were evaluated during the field research for the Safety Check design. The odorants included: aromatic oils (peppermint, eucalyptus); perfume; incense (sticks and cubes); hydrogen disulfide wrapped in combustible material; crushable ampoules of banana oil (often used for checking the fit of respiratory apparatus); and butol-mercaptan or skunk odour (often used in laboratories to detect air contamination).

The ideal substance for an odorant would be one which could be placed in the combustion chamber or chambers of a furnace and would then release a steady and sufficient quantity of odorant over the period of a full cycle of furnace operation, without any change in the constitution of the odorant while flame is operating. The most successful of all the odorants evaluated appeared to be the incense sticks. Incense has a distinctive odour even in very minute quantities, continues to burn at a steady rate over a period of many minutes, is easy to obtain and locate, is not significantly altered by the flame of the furnace, and produces a visible smoke, which makes it easy to determine if any accidental spillage occurs during the test. However, all of the odorants evaluated -- including incense -- suffered from several major problems as a test technique.

The greatest problem was the subjective nature of the test: it relies on a very qualitative measurement of leakage area. Once an individual has received even a small indication of the odour, either through spillage or through very small leakage, or even through handling the materials prior to the commencement of the test, this can be enough to desensitize the olfactory glands and warrant the remainder of the test invalid.

Another problem was the very uneven mixing that occurred in placing odorants in the combustion chamber; there could very well be very large leaks in the heat exchanger that were outside the stream from the odorant, and thereby would go undetected.

A final problem is that the odorant is not sufficient to show small leaks in a heat exchanger since, under most operating conditions, the leakage will be from the circulating household air into the combustion chamber and up the chimney, and would therefore not permit detection of odors by individuals inside the house.

2.44 Trouble-light Investigations -- Depending on the design of the furnace, it is sometimes possible to use light as an indicator of leakage. This technique is more suitable for oil furnaces than gas furnaces, since, in an oil furnace,it is sometimes possible to see large areas of the heat exchanger from above. If a trouble-light is placed in the combustion chamber and turned on, any light entry that appears through the heat exchanger walls, from above or behind, would be indication of a leakage point.

A variation of this technique is used in CGA cyclic testing of gas furnaces, where a fluorescent tube light (similar to that used for automobile engine inspections) is inserted into the combustion chamber. A colored penetrating oil can also be applied to the reverse side of the heat exchanger, to highlight any hairline cracks.

The use of lights, for heat exchanger inspections, is an excellent means of identifying leaks quickly and accurately. Unfortunately, the area of the heat exchanger which can be examined by this technique is limited to much less than half the total area, which makes the test only partially adequate. Moreover, in a conventional gas furnace, there is no easy access into the plenum area above or below the heat exchanger, or on the back or sides.

2.45 Carbon Dioxide Sampling -- Carbon dioxide sampling of the circulating air in the warm air plenum can provide a reasonably sensitive indication of contamination by combustion gases. Sampling is most easily accomplished using a hand held pump connected to colorimetric detector tubes. The two most common commercial systems are Drager and Gastec. Both manufacturers produce a low- range CO2 tube using the same reagent, and both tubes are capable of accurately indicating concentrations of CO2 below ambient levels, (Drager Cm30802, and Gaster 2LL). Color staining on the tube gives a direct reading of CO2 in ppm .

The sensitivity of these tubes was evaluated in the field and found to adequately reveal the presence of combustion gases. A 37mm diameter pipe was used to connect a combustion port with the return air plenum. CO_2 levels were then found to measure more than twice ambient in the warm air plenum. CO_2 sampling has been used occasionally, by field inspectors, for diagnosing pollution complaints. The tubes work well in cases where an extreme failure exists. Regular use by gas services is not common, possibly due to the cost of purchasing tubes and maintaining the equipment, or a lack of trust in tubes, or perhaps difficulty encountered in remembering the correct sampling procedure.

The difficulty with detector tubes is that they can only indicate a failed heat exchanger if a significant amount of combustion gas happens to be leaking into the forced air system. Since the direction of leakage is usually the other way, the tubes are useful only in diagnosing extreme failures.

2.46 Smoke Candles -- A smoke candle or a smoke bomb is a device that can be lit to generate large quantities of highly visible smoke. The use of smoke candles is fairly common during testing the integrity of large heat exchangers on commercial heating systems. Typically, the smoke is generated, in the combustion chamber, for a period of 30-60 seconds, or even for several minutes. Leakage or spillage problems around the appliance becomes visible immediately. After the smoke has filled the entire combustion chamber, the forced air system can be manually operated, circulating leaking smoke (in lieu of combustion gases) through the heat exchanger to warm air registers, where it should still be visible, if the leakage area is large.

The use of smoke candles was found to be inappropriate, in gas furnaces, during the field research. The first problem was the excessive quantities of smoke generated by the currently available smoke candles. The shortest time duration of the smoke candles appears to be 30 seconds, over which time the candle generates a total of over 4000 cu. ft. of smoke. Since a smoke candle of this type must be placed in each of the combustion chambers of a gas furnace, the quantity of smoke is multiplied by the number of ports. It is impossible, therefore, for the gas furnace, even when the heat exchanger and chimney are hot, to exhaust such a quantity of smoke that the inevitable result is spillage through the primary and secondary air inlets, or through the dilution air inlet. When smoke spills out the front of the furnace, it quickly invalidates the test, by obscuring the furnace, and by being sucked into the circulating air system and distributed throughout the entire house. The only alternative is to place a single smoke candle in front of the gas burners, and tape over all the openings in the furnace, (a time consuming and impractical approach).

Discussions with manufacturers of smoke candles indicated that it might be possible to manufacture a smoke candle which generated much smaller quantities of smoke over a reasonable period of time, and may therefore make possible the testing of combustion ports in gas furnaces.

Other problems were encountered with the use of smoke candles. At $3 apiece, the cost of testing a gas furnace, for leakage, may become unacceptable.

To avoid spillage around the furnace, during a test, the chimney must be open and hot to ensure exhaust, and thus the entire test must be conducted while the combustion chamber is undergoing at least some amount of depressurization. Although it is possible to conduct a smoke candle test with the burner and the blower off, there is more likely to be a negative pressure in the combustion chamber, relative to the house circulating air, and consequently smoke will never leave the combustion chamber - to indicate whether or not there are leaks. If smoke were seen to spill from the dilution air inlet, it would be unclear whether the problem was the generation of smoke exceeding the draft capacity of the chimney, or leakage and forced air entry into the combustion chamber, resulting in spillage of smoke and, presumably, combustion gases.

The use of smoke candles, on oil furnaces, is somewhat more appropriate, since a single smoke candle can be lit and placed in the combustion chamber, through the inspection port, and the port then closed. This can be done while the furnace is warm, but not operating. The smoke will entirely fill the combustion chamber, prior to moving up through the heat exchanger and exhausting out the chimney. If leakage exists in any of these locations, it is possible that some amount of smoke might enter into the house. The possibility is greater if the draft of the chimney is reduced through partial sealing of the chimney opening, (although this is a difficult procedure to follow on site). Since the smoke candle can be operated for a period of a minute or more, in an oil furnace, it is possible to test for leakage under all ranges of operating conditions of the furnace, and thereby determine if the potential exists for contamination from that furnace. While the smoke candle may not indicate if a leak exists in the heat exchanger, it may well be a valid test of whether potential contamination can occur.

A further problem with the use of smoke candles, in testing for heat exchanger contamination, may be damage from the constituents of the smoke. The smoke candles, investigated for the purposes of this study, produced either a zinc- chloride mist, or a titanium tetrachloride mist. In either case, the thin film of this substance, on the inside of the heat exchanger could, over time, exacerbate corrosion problems, through ionization. This could lower the overall life-expectancy of the furnace, especially in a gas furnace where there would be little insulation over the metal heat exchanger. This possibility of corrosion raises doubt about the advisability of the technique.

2.47 Sodium Salt Spray -- This is a sophisticated procedure that has been developed by BC Hydro, for testing potential leakage in the heat exchangers of gas furnaces. The technique involves spraying a 10% solution of sodium carbonate (Na_2CO_3) into each port of a gas furnace, while the furnace is firing. The Na_2CO_3 is quickly vaporized inside the heat exchanger. While the spraying takes place, a propane torch is lit and either held at the warm air registers of the house or, preferably, connected to the warm air plenum directly above the furnace. If the air stream in the warm air plenum has been contaminated by the Na2CO3, as a result of some leakage in the heat exchanger, the effect will be to turn the blue propane flame to orange or yellow. The extent and duration of color change in the flame is an indication, to the tester, of the quantity of leakage that is taking place.

The sodium salt test was further developed during the field research and was evaluated, on many houses across Canada, at the same time. Special propane torch heads were required for this purpose. These torch heads were required for this purpose. These torch heads are designed for those refrigeration companies that use the propane test as a way of detecting freon leakage in refrigerator systems. The torch heads have a hose which supplies the majority of primary combustion air to the propane flame and makes possible the gathering of combustion air from any particular location.

The sodium salt test suffers from a number of problems, when used as a comprehensive test of heat exchanger leakage. The test requires that the furnace flame be operating. Consequently, much of the combustion chamber will be at a negative pressure relative to the house circulating air, and sodium will not become apparent regardless of major leakage area.

Another problem with the test is that the drawn through air the propane flame must sample all the air in the furnace plenum. If the sample air is drawn only from one location of the circulating system, it may be that the Na2CO3 is missed entirely, as it rises or is forced in another direction.

An additional problem with using the sodium is the tendency of propane flames to turn yellow with any amount of contamination: the tester must be very careful not to knock or disturb the furnace circulating system during the test, since this will increase the quantity of particulates circulating in the air and provide a degree of distortion and yellow flame.

Because the sodium salt test is a reasonably quick and convenient procedure, and because it does provide a visible and objective indication of potential contamination through the walls of the heat exchanger, the test is felt to have some potential.

2.48 Smoke Pencil Kit -- The most appropriate technique, for identifying leaks, appears to be testing with smoke pencils, while the combustion chambers are pressurized. This technique was developed during the field research for the Safety Check, and appears to work quickly and effectively in almost all cases. The only difficulties encountered with this test were the difficulty of safely plugging the chimney, and the necessity to find the switch to manually operate the furnace blower. The furnace chimney is plugged to prevent chimney draft from distorting air movement through the heat exchanger.

The chimney is plugged with the aid of balloon flue sealers, and the blower is operated by means of the "summer" switch. With the chimney plugged and the blower operating, it is possible to use smoke pencils to inject a stream of smoke into the heat exchanger combustion ports, or around the inspection port of an oil furnace combustion chamber. By observing the movement of smoke while the blower is off, and also while it is on, it is possible to determine if any significant amount of household air is being forced into the combustion chamber, as a result of leakage in the heat exchanger. The use of smoke pencils on gas furnaces requires the addition of an extension kit on the smoke pencil, consisting of flexible plastic tubing, copper tubing, and a pen light. This equipment makes it possible to examine both top and bottom ports.

The value to the test is that it is a quick, convenient, and seemingly reliable method for indicating the existence of leakage area. A minor problem with using the smoke pencil kit is that the heat exchanger must be tested while it is completely cold to avoid convection currents which would distort the smoke test. A cold heat exchanger may have cracks that are closed because the metal has not yet expanded. In the opinion of many service personnel, the cracks and holes in a heat exchanger will open up somewhat as a result of heating the furnace. The extent to which cracks in a heat exchanger will open or close with temperature has not been demonstrated. In some cases cracks might close as the heat exchanger heats up. In any case, it is assumed that significant leakage area will remain open under both cold and hot conditions.

A second problem that was encountered, with the use of smoke pencils for testing furnaces, was the somewhat subjective nature of evaluating the extent of leakage. A properly completed smoke pencil test can identify even tiny leaks in a heat exchanger, but it was often difficult for field personnel to decide whether small quantities of leakage were in fact sufficient to condemn the furnace, or to warn the householder. For purposes of field evaluation, personnel were advised to ignore any movement of smoke, caused by leakage, unless there was a continuous, steady movement of air out of the heat exchanger. If the disturbance of smoke was questionable or very slight, then it was deemed to be acceptable. Service personnel witnessing the test felt that it was important not to condemn furnaces, or alarm householders, as a result of tiny amounts of leakage detected in this way. The sensitivity of the test requires a judgement call from the tester.

During the development of the smoke pencil test procedure, an effort was made to determine the minimum detectable size of leakage area. A 25-mm diameter copper pipe was connected to the warm air plenum, immediately above the furnace, and then run through the combustion port, to the lower back portion of the heat exchanger. When the circulating blower was operated, household air was forced through this tube, and the heat exchanger was pressurized, as if a hole existed in the back. This 25mm opening created a dramatic effect on the smoke plumes and would, under any conditions, be identifiable. The size of the tubing was reduced by taping over a portion of the outlet. The tubing was then reinserted down into the center of the heat exchanger, and the blower once again operated. In this way it was possible to determine that even 1cm^2 of leakage area could be detected using the smoke plume technique. It was noted, during these tests however, that the location and direction of flow through the tubing opening would sometimes cause air to exfiltrate through the intake ports, and at other times through the exhaust ports; it was thus necessary to smoke test in both locations.

Early experiments, on pressure differences across the walls of heat exchangers, had indicated that there is likely to be significant negative pressure inside the heat exchanger, relative to the house circulating air. Thus it is presumed that the test should be adequate to identify leakage anywhere.

A minor difficulty with the test procedure was the effect of leakage around the edges of the heat exchanger (joins with plenums, furnace casing, and blower compartment). A significant amount of leakage into the circulating system, through cracks in these joins, could distort the test, and it is therefore necessary to inject smoke slowly, directly into the heat exchanger itself, to determine that the leaks are occurring in the walls of the heat exchanger. At the same time, it should be noted that a significant amount of leakage, around the front perimeter of the heat exchanger itself, can cause venturi effects around the gas ports, and scour or distort the air flow into the heat exchanger. Serious leakage of this sort has been implicated in CO poisoning incidents, and it may be wise, in fact, to use the smoke pencil test both as an indicator of leakage potential inside the heat exchanger, and as an indicator of the excessive plenum leakage around the outside perimeter of the heat exchanger.

2.5 REMEDIAL MEASURES FOR LEAKY HEAT EXCHANGERS

In most cases, the appropriate remedial measure for a failed heat exchanger is to replace the furnace. The relatively low cost of conventional furnaces usually makes this approach more cost-effective than trying to repair an existing furnace.

Under certain circumstances, other remedial measures might be considered. If the furnace is under warranty, it should be repaired or replaced by the manufacturer. If the leakage is entirely as a result of gasketing that is loose or missing around the edge of the heat exchanger, it would be a simple procedure to repair the gasketing. If the leakage is a result of thermal stress or corrosion inside the heat exchanger, it is probable that the best approach is to remove the furnace, even if it is relatively new.

Furnaces older than 5 years are seldom worth repairing, since the lifespan may be reduced as a result of the existing damage and ensuing repair work. The effort required to expose the heat exchanger, and repair leaks, could involve a day's labour, with costs comparable to replacement. In summary, unless the furnace is less than five years old, or under warranty, and unless the leakage is easily identifiable and easily repairable, it is recommended that significant leakage be remedied by replacing the furnace.

If leakage in the heat exchanger is the result of thermal stress on an older unit, remedial measures other than heat exchanger replacement are not required. In some cases, however, a faulty heat exchanger is an indication of problems in the design, installation, or surrounding environment, and additional measures may be appropriate. Corrosion problems, for example, warrant further investigation.

Unfortunately, furnace servicer's seldom take the time to determine the location, size, and cause of the leakage. (Use of the smoke pencil test kit will identify the specific chamber, or chambers, at fault in a gas furnace, and is a good first step.) With more time spent on proper diagnosis of the problem, preventative measures might be considered. For example, where corrosion has occurred because of halogenated hydrocarbons, or salt spray, excess humidity, or some other environmental factor, a preventative measure might consist of constructing a furnace room and installing a suitable combustion air intake.

3.0 BROKEN, BLOCKED AND POORLY DESIGNED CHIMNEYS

3.1 Failure Mechanisms:

When an imbalance exists between the firing rate of a furnace and the exhaust capacity of a chimney ventilation system, the result may be spillage of the combustion gases into the house. The carrying capacity of a chimney ventilation system will depend on the draft that exists in the chimney and the cross-sectional area of the chimney. A reduction in either of these factors may cause spillage and, even if these two factors remain constant, spillage can occur as a result of over-firing of the furnace, since over-firing can increase the requirements for exhaust capacity.

In a conventional gas furnace, the ratio of fuel to air is typically about 1:30. Slightly more than half of the air requirement is intended to ensure proper draft at the dilution air inlet opening. The remainder is comprised of primary and secondary combustion air, which enters the furnace around the gas venturi jets. For example, a 100,000 BTU gas furnace would require approximately 5 L/s of primary air, 7 L/s of secondary air, and 15 L/s of dilution air. The chimney must, therefore, exhaust a minimum total flow of approximately 30 L/s. As a chimney's capacity drops below this point, the result may not immediately be spillage. Initially, the effect will be to reduce the quantity of dilution air entering at the dilution air inlet. There is also likely to be an increase in temperature in the flue, with a compensating increase in total chimney draft.

Spillage will not occur, through the dilution air opening, until the chimney's carrying capacity is reduced to less than the load required to handle the primary and secondary combustion air load.

Often the spillage that occurs, through the dilution air inlet of a conventional gas furnace, will be a function of the start-up period only. At the moment the furnace is fired, the low draft in the cool chimney is unable to carry the total exhaust flow. Only a small portion of the exhaust flow may rise up the chimney. However, the initial exhaust gases rise through and warms the chimney, increasing draft -- usually to the point where the total exhaust flow is sufficient to vent the furnace without spillage. Transit time of gases, in a chimney with low draft, is rarely more than several seconds in total, and consequently the phenomenon of start-up spillage is normally restricted to the first 5 or 10 seconds of furnace operation.

Spillage can also occur in a conventional oil furnace, on a continuous basis, or during the start-up period. Gun-type oil burners have a squirrel- cage fan that provides a degree of forced air draft on start-up. The operation of this fan helps to ensure proper mixing and ignition of oil, and a rapid movement of hot combustion gases into the flue, where they can increase the draft and adequately exhaust up the chimney. However, a low draft condition, at the point of ignition, can initially create a back-puffing phenomenon, wherein the products of combustion are forced out of the combustion chamber, through any cracks and holes, (e.g. the inspection port).

Back-puffing is usually limited to the first few seconds of start-up; but if low draft, constrictions, or breakage in the chimney continue to create a condition where the total exhaust cannot be exhausted, the spillage will begin to occur along the flue connector and through the barometric damper. Essentially, a portion of the flue connector will be pressurized by the air supply fan of the burner, and spillage will occur wherever leakage exists.

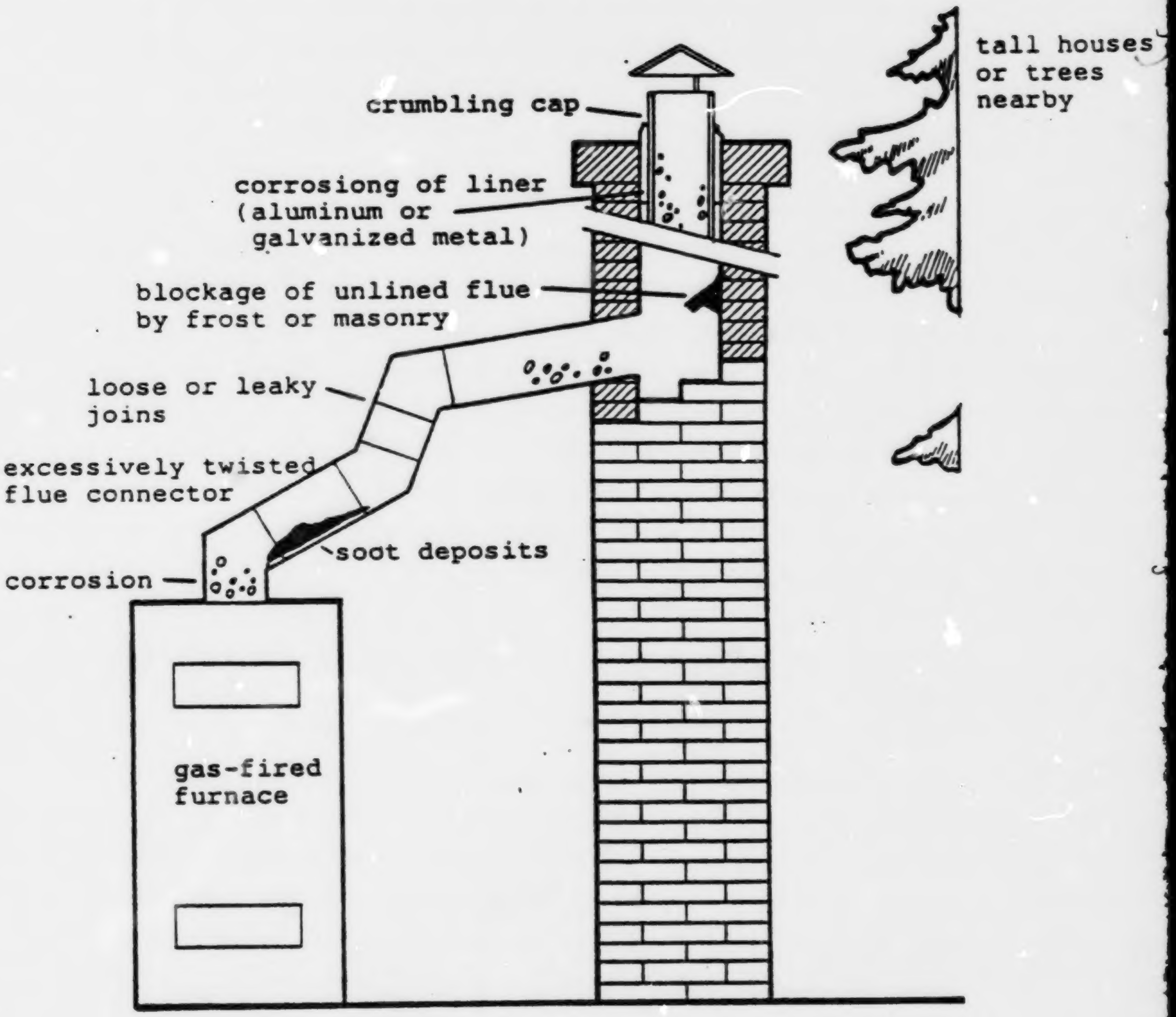
In both gas and oil furnaces, continuous spillage of combustion gases, into the furnace room, may result in recycling of these gases through by the furnace burner, with subsequent lowering of oxygen levels, and eventual production of CO.

3.2 Factors Contributing To Chimney Spillage

Some of the more common factors contributing to chimney spillage are briefly described below:

3.21 Blockage of Flue Due to Masonry -- Masonry materials, including broken pieces of clay tile lining, loose brickwork, or pieces of the chimney cap, can lodge in a flue opening and constrict the flow of gases. Most commonly, it will be portions of the chimney cap which deteriorate with time and, when broken, fall into the chimney. Chimney linings can also break apart and lodge in the chimney opening, especially when subjected to stress from condensation, freeze-thaw cycles, or shifting masonry in a poorly supported

Figure 6


crumbling cap
corrosiong of liner (aluminum or galvanized metal)
blockage of unlined flue by frost or masonry
loose or leaky joins
excessively twisted flue connector
corrosion
soot deposits
tall houses or trees nearby
gas-fired furnace

CHIMNEY PROBLEMS THAT CAN LEAD TO SPILLAGE OF COMBUSTION GASSES INDOORS chimney. Typically, a masonry chimney is constructed with a stretch of flue below the thimble (where the flue connector is attached), and an ash clean-out drawer at the bottom. This ensures that, if any masonry falls freely down the chimney opening, it will not block essential portions of the chimney opening. If considerable quantities of masonry fall down in this fashion, however, the lower portions of the chimney are filled up and eventually block off the opening into the flue connector.

3.22 Blockage Due to Birds & Animals -- Another source of chimney blockage is birds. The warmth of the chimney provides a cozy nesting situation, and in fact, nests may be constructed during the summertime, when chimney operation does not bother the bird or its family. There are some reported incidents of bird or animal bodies blocking flues. On cold days, birds will often stand on top of a chimney to keep warm and, possibly in a drugged and sleepy condition, it is easy for a bird to lose its senses and fall victim to the combustion gases. Most bird bodies are too small to seriously block a flue, although seagulls have been known to completely plug chimney openings.

Squirrels, bats, bees, and other wildlife can also create blockage in the flue opening.

3.23 Blockage Due to Ice Accumulation -- Heavy condensation in flues, during cold weather, can cause an accumulation of ice, constricting or even blocking in the chimney. Ice accumulations are more common in gas heating systems, than with oil, due to the lower operating temperatures. Masonry chimneys are a problem because of a larger flue gas volume, lower surface temperatures, and greater thermal mass. On a lined chimney, the greatest amount of condensation is likely to occur at the top of the chimney, where the flue gases and chimney are both at their coldest. Excessive deposits of moisture, on the chimney cap, can block the opening. Gas furnaces, that have been installed into unlined masonry chimneys, also suffer from ice accumulations, although these can occur up the entire flue, due to the cold masonry. Leakage through the masonry will exacerbate icing problems. Accumulations of ice inside a masonry flue can break down the masonry or clay tile lining, and then ice, combined with tile or masonry, can break free and plug the flue.

3.24 Blockage Due to Soot Accumulation -- Heavy accumulations of soot, in flue connectors or chimneys, can cause spillage, by constricting the flue opening. Sooting is a relatively rare phenomenon with gas furnaces, but can occur as a result of poor combustion, caused by dirty or misaligned gas jets, or inadequate primary air supply. A luminous, smoky flame causes soot to accumulate in the heat exchanger or the flue connector. As the draft is reduced, the rate of generation of soot can increase, until eventually the constricted flue causes spillage. A common situation, reported by inspectors, is the blocking of floor level air intake for a hot water heater burner, by pet hairs, dirt, or small objects. The soot from the defective flame eventually plugs the flue connector of the water heater (and possibly the flue connector of the furnace as well).

Sooting of an oil furnace is a regular process that requires annual maintenance, to ensure that the quantities of soot do not lower the heat exchange efficiencies or potentially block off the flue connector. Production of soot, in an oil furnace, will be greatest when the oil spray is impinged, usually because of an improper spray angle. Sooting occurs as the oil contacts the side of the combustion chamber, or the flame spread head. As soot accumulates, the problem degenerates.

Heavy sooting can also occur during start-up and shut down periods. At start-up, the burner fan has not managed to maintain a proper air flow and mixing pattern, and combustion is incomplete, for the first few seconds. After shut-down, the conventional oil pump will permit some siphoning of oil smoking and coking can occur for several seconds. Soot accumulations, due to poor start-up conditions, are usually not sufficient to create a serious problem, unless the furnace is regularly starting up against low draft or backdraft situation. Frequent, low-draft conditions will deposit soot in flue connectors and can, over short periods of time, create a serious constriction of the flue pipe, leading to spillage problems.

3.25 Undersized Flue Connectors -- The flue connector, attached to the furnace, must be balanced to the firing rate of the appliance. Systems that have not been properly installed and inspected may be inadequate, as installed. Changing appliances, without recalculating proper flue sizes, or adding additional appliances (such as a water heater) to existing flue connectors, are common occurrences which lead to undersizing of a flue connector.

3.26 Design Flaws -- A common design flaw in chimneys is excessive length, or low slope, of flue connectors. Connecting two or more water heaters, to a furnace flue connector, has also created spillage problems. Long flue connectors, and low slopes, lower the total draft of a chimney system, due to air-flow resistance, heat loss, and infiltration. Connecting additional appliances to a flue connector creates momentum drag, also lowering effective chimney draft. The effects of conductive heat transfer, across the wall of the flue connector, combined with infiltration of house air into the flue gas stream, will further lower the total chimney temperature and draft.

The recommended installation guidelines and design tables, in the CGA Natural Gas Appliances Installation Manual (Section 8) are intended to help installers avoid these problems.

3.27 Overfiring of Appliance -- If the fuel delivered to the burner of a furnace exceeds the design specifications, the effect can be spillage at the chimney opening, or spillage around the primary/secondary air intakes. Overfiring of a burner can occur when an existing orifice or nozzle is replaced by an oversized unit. It is also possible for the existing orifice or nozzle to be defective and allow excessive amounts of fuel into the combustion chamber. Overfiring can also occur if the pressure in the fuel line is much higher than usual. This is more common on an oil furnace, where a faulty oil pump can create high pressures. Pressures will often fluctuate on natural gas systems, as well, although usually not more than 10-15 percent. Gas valves in furnaces are designed to maintain a constant pressure at the manifold. However, the valves are rarely checked for overfiring by the furnace manufacturer, or the installer.

3.28 Broken or Leaky Connector -- If a flue connector is not tightly secured in all its sections and properly fitted to the vertical chimney, the effect may be to permit some amount of spillage as the combustion gases rise and are exhausted form the house. The most common situation is for a flue connector to be poorly connected at the thimble (where the connector joins the vertical chimney). If the flue connector is significantly mis-aligned, the effect will be to lower draft or create partial blockage , which, in turn, results in spillage. This spillage can be significant and will occur regardless of whether or not spillage is evident at the dilution air inlet opening (or the barometric damper).

3.3 FREQUENCY AND SEVERITY OF CHIMNEY SPILLAGE PROBLEMS

The Hatch Report, on Hazardous Heating And Ventilating Conditions in Housing, concluded that collapsed, dislodged, blocked, or damaged chimneys accounted for approximately 31% of all CO incidents in Canada, reported over the last ten years. The problems of chimney spillage appear to be particularly prevalent in Ontario and Alberta in this study, although data was not available for all regions of the country. According to the study, the improper installation of chimneys, vents, and flues accounted for another 24% of all reported incidents. On the basis of the Hatch Report, then, chimney spillage problems resulting from inadequate chimneys account for more than half the reported CO incidents.

Chimney spillage is a particularly serious type of vent malfunction, in a tight room or tight house, because it can quickly lead to CO production. Initially, spillage will produce little, if any, CO, but as the gases are recycled through the furnace, Co concentrations increase at an exponential rate. The longer the appliance run-time, the much greater the possibility of a serious health risk.

3.31 Monitoring CO Concentration Indoors after Chimney Blockage

Experiments were completed during the field research for this project, to determine the potential for CO production during chimney spillage conditions. A Miran A-1 infrared analyzer was connected to a strip-chart recorder, and placed so as to continuously sample household air in an open basement, next to a furnace with a blocked chimney. The house was a 117 m2 bungalow with an ELA of 2800 cm2. The weather was calm and 12oC.

The furnace was fired for a period of 60 minutes and CO levels were monitored, along with relative humidity and carbon dioxide. Monitoring was also conducted on the main floor level. Gastec colorimetric tubes were used to corroborate the Miran measurements.

Throughout the entire monitoring period, CO concentrations in household air were so low as to be undetectable, except in the joist area of the basement ceiling directly in front of the furnace, where levels of CO stabilized at 9 ppm. Within 30 minutes of operation, the house temperature had risen from 18oC to 26oC, the relative humidity had risen from 58% to 100%, and CO2 levels had.risen from 700 ppm to 3500 ppm.

The absence of CO in these experiments can be partly explained by air flow patterns in the house. As hot gases spill from the dilution air inlet of the furnace, they quickly floated upwards, exfiltrating through the upper portions of the hours, due to increasing stack forces. The forced air system contributed to thorough mixing on the main floor level but, in the basement, the predominant pattern was infiltration, bringing cool fresh air through leakage openings around the foundation walls. The location of the furnace burner, so close to the floor, ensured a continuous supply of fresh air, with no recycling of combustion gases.

This case study illustrates how important building airtightness is in the determining of the potential for CO production during chimney spillage. More experimentation is required, before it is possible to identify conditions which might allow hazardous concentrations of carbon monoxide to be produced.

3.4 IDENTIFICATION OF CHIMNEY SPILLAGE PROBLEMS

A standard approach for checking chimney systems, for spillage problems, is to examine the components of the chimney system (for obvious signs of dislocation, blockage, collapse, or faulty installation and design), and then check for spillage or improper draft, during operation, using a flame (or smoke pencil).

Because so many factors can be implicated in spillage problems, it is important that the inspection and spillage check be standardized and comprehensive. All possible combinations of operating conditions and spillage locations should be included. For example, spillage could occur: only at discreet locations along the chimney; only during the start-up period; only with both the furnace and water heater operating; or only under specific weather conditions.

Once a chimney spillage problem occurs, it may be too late to avoid damage to health or safety. Preventative maintenance is required, and the inspection routine must consider the potential for sudden blockage, collapse, or other catastrophes that would provoke spillage.

3.41 Visual inspections

A cursory visual inspection is sufficient to determine whether a chimney meets with code requirements, and is properly fixed and supported. Inspecting inside the flue connector and chimney is more complex. Ideally, the flue connector should be dismantled and thoroughly examined, from both ends with a flashlight. Once the flue connector has been detached from the chimney, it also becomes possible to thoroughly examine the base of the chimney itself, using a furnace inspection mirror and a flashlight. Upper portions of a chimney, are best examined after climbing onto the roof. A thorough examination of the cap is then possible, and the lining can be surveyed, by dropping a trouble light on a rope, and looking for signs of condensation, cracking, leakage, heat stress, sooting, etc.

Unfortunately, completing such a thorough inspection of the chimney is often impractical. Time requirements will vary, but removing sheet metal screws, dismantling flue connectors at both ends, clean-up and so on, will result in an inspection time of over an hour. Climbing roofs is dangerous, and sometimes necessitates time-consuming safety precautions, like scaffolding, and the involvement of more than one individual.

Instead of dismantling the flue connector, a more convenient approach is the use of an endoscope, with a fibre optic light source. The endoscope is an adjustable periscope, with a self-enclosed, back-lighting system. A 1 cm (3/8") hole is punched into the flue, near the chimney base. The endoscope is then inserted through the hole and, by adjusting the dials around the eyepiece, it becomes possible to look up and down both the flue connector and the vertical flue. Unfortunately, the use of endoscopes, for chimney inspections, is limited, because the cost is presently $1,000 to $1,400 per unit.

Use of a furnace servicer's mirror is more cost-effective than an endoscope. The mirror works exceptionally well in Class A masonry chimneys, where removal of the ash cleanout door provides easy access into the vertical flue. This approach provides information on the condition of the ash cleanout, a good idea of the state of the chimney lining the base, and a clear profile of any obstacles in the flue (silhouetted against the sky).

With oil furnaces, it is usually easy to remove the flue connector, both at the thimble and at the breach. On gas furnaces, because of large numbers of sheet metal screws and the difficult joining of tight stovepipe, the dismantling of the flue connector is less practical. A furnace servicing mirror can be used only to inspect the flue immediately above the dilution air inlet opening. However, an interior inspection of a B-vent may not be essential, since there is little likelihood of obstacles, and serious problems should be visible at either end of the chimney (e.g. staining, sooting).

Roof top inspections of chimneys may be warranted only if deterioration is already evident from a distance, or if problems exist at the lower end of the chimney, or if spillage is observed under operating conditions.

3.42 Performance Testing for Chimney Spillage

In order to determine the existence of adequate draft in the chimney, it is necessary both to check for spillage at the dilution air inlet and at other joints along the flue, and to determine the quantities of excess air in the combustion gases. Even if no spillage is apparent during operation, it is possible that chimney draft is inadequate, since a minimum amount of excess air is required for efficient and safe operation.

Unfortunately, techniques for determining the percentage of excess air, in combustion gases of gas-fired appliances, are difficult to use on-site. Two common approaches are measurement of temperature and measurement of C02 content. These measurements must be taken inside the heat exchanger ports, as well as above (downstream) of the dilution air inlet opening. An attempt to follow this procedure in the field, on a number of furnaces, has indicated that, due to the extremely poor mixing that takes place in the flue, such identification techniques are inappropriate.

Checking for spillage from a flue, during operation, requires the use of either a flame, or a smoke generating device. Smoke pencils, or smoke guns, provide the most visible indication of air movement. They also allow an inspector to quickly determine if spillage is occurring in any location. Use of a flame (a disposable lighter or a match) can be a little more difficult, since the high velocity of air streams will often extinguish the flame; flames also require a more subjective evaluation, as the flame itself generates a considerable amount of heat and air movement and, only by observing the tip of the flame is it possible to actually evaluate draft around the flue.

Since spillage may occur only during the start-up period, a check for spillage should begin when the chimney is cold and under worst-case conditions (wherever possible). From the perspective of chimney draft, worst-case conditions would require a check on a warm day, with the house as tight as possible, and with all the exhaust systems in the house operating. In this way, the availability of draft air for the furnace is reduced to a minimum. In fact, in some cases, the chimney may be backdrafting due to the depressurization of the furnace room. A spillage check must incorporate the initial backpuffing and spillage, as the furnace will take some time to establish adequate draft. In most situations, it is feasible to fire the furnace under worst-case conditions -- while standing aside to avoid the worst effects of back-puffing -- and time the duration of the spillage.

Because spillage will not necessarily occur first at the dilution air inlet opening, a flame or smoke should be used to evaluate the draft along the entire length of the flue connector, including joins and thimble, any connecting flue from the DHW, and any join from the flue connector to a B-vent. If spillage is observed under these conditions, at any of the locations, the test can be repeated with an outside door or window open. If the spillage persists, the condition is not related to low indoor house pressures, but may be a result of a damaged, dislodged, constricted, or broken flue.

3.5 AVOIDANCE OF SPILLAGE PROBLEMS

Because of spillage problems can occur as a result of many different factors, there is no short list of remedial measures. Selecting the most appropriate remedial measure requires proper diagnosis: a blocked chimney needs the obstacle removed; a dislodged chimney needs proper attachment, etc.

Also important, in remedying spillage problems, is the implementation of preventative measures. For example, if the chimney were blocked due to animals in the flue, a preventative measure would be the installation of screening at the chimney top, an icing chimney might require a proper lining; a heavily sooted chimney might require a new valve (or nozzle) and proper cleaning and maintenance of the furnace burner, etc.

In some cases, there may not be a specific explanation for spillage conditions. In other cases, remedial measures may exceed the householder's budget. A "cookbook" approach to problem solving is needed, similar to what is outlined in Section 1.5, Remedial Measures for Backdrafting Chimneys.

RESIDENTIAL COMBUSTION SAFETY CHECKLISTS

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APPENDIX IV

REMEDIAL DEVICES

- Forced and Tempered Air Supply -
- Chimney Failure Alarm for Gas-fired Furnaces -
- Fail-Safe Spillage Switch for Gas-fired Water Heaters -

Prepared for:

The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

by:

Sheltair Scientific Ltd.

March, 1985

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REMEDIAL DEVICE 1: A FORCED AND TEMPERED AIR SUPPLY SYSTEM

1.0 INTRODUCTION

The object of the apparatus developed in this project was to prevent the possibility of furnace backdrafting by using a fan to supply air to the house and pressurize it. This fan must operate whenever there is a danger of backdrafting of either a fuel-fired furnace or a fuel-fired hot water heater.

Two problems were faced in developing the apparatus to do this job. One was to ensure that the fan will always run when required, but will not run any more than necessary. The second problem was to warm the air introduced into the house so that it would not cause discomfort.

The solution to the latter problem was to place a 5 kW electric heater in the warm air stream. This heater is proportionally controlled to heat the air to room temperature, but no higher.

The solution to the former problem was to interlock the fan with all the exhaust fans in the house, with the clothes dryer, and with a manual switch next to the fireplace.

The resulting design is presented in Chapter 3.0 of this report. The rationale for the design chosen is discussed in Chapter 2.0. This design is far from optimized. It is simply the best that could be achieved within the time and budget constraints of the present project.

Within these constraints it has been possible to assemble the apparatus which was designed, but not to install it in a house and test it. This installation has been planned in detail, but further work will require further funding.

2.0 DESIGN RATIONALE

2.1 Supply Fan Control Strategy

The primary concern in developing the supply fan control strategy is safety. A device installed in houses with potential backdrafting hazards must not lull householders into a false sense of security. It must provide real security without fail. A second concern is first cost. The total cost, for equipment and installation, must be as low as possible. The third concern is operating cost. The supply fan system uses electrical energy to heat the makeup air, and this energy may be more expensive than the heat supplied by the furnace. The system must introduce the minimum amount of air which can satisfy the safety criterion, to minimize this energy use.

We have considered four possible supply fan control strategies. They are as follows:

1. Connect the supply fan to the exhaust fans. The supply fan would operate whenever any of the exhaust fans were turned on.

2. Detect a negative pressure in the house. If the pressure in the house became negative relative to the atmosphere the supply fan would operate.

3. Detect a low temperature in the chimney. Upon sensing an abnormally low temperature in the chimney during furnace operation the supply fan would activate.

4. Detect downflow in the chimney. A paddle sensor could detect a downward flow from backdrafting of or in the chimney and activate the supply fan.

Strategy 1 is the simplest to implement and has the lowest equipment cost. However, its installation cost is high because of the need to fish control wires throughout the house. Also its operating costs will be high because it activates the supply fan whenever any of the exhaust fans are operating, not just when they are causing a backdraft and the furnace or hot water heater is firing.

Strategy 2 requires a rather sensitive switch, which raises the issue of reliability. This strategy only activates the supply fan when a negative pressure actually occurs, so it saves energy relative to Strategy 1. It will still allow the supply fan to run when the combustion devices are off, although this could be prevented by an interlock to the house thermostat and to a thermocouple or thermistor in the hot water heater. This strategy will not prevent spillage, but only backdrafting of the chimney.

As part of this project a search was made for a pressure switch sensitive enough and cheap enough to be used, but none was found, so this options was rejected. Since then, a suitable switch has been found, although it is still under development by the manufacturer. A prototype has been ordered.

Strategy 3, like Strategy 2, could be linked to the operation of the combustion devices to minimize fresh air intake. Like Strategy 2, it would not detect spillage, only full backdrafting, although it could be combined with a second temperature sensor near the dilution air inlet of each combustion device, to detect spillage.

Strategy 4 could also be linked to the operation of the combustion devices to minimize fresh air intake. Strategy 4 was rejected because sail switches sensitive enough to detect low velocity air motion are too sensitive for this application.

In conclusion, Strategy 1 will possibly cause unnecessary fresh air intake which could be avoided by Strategies 2 or 3, but it has been adopted for the present because: it is reliable, can be implemented without further research and development or work, and uses widely available components.

2.2 Fresh Air Preheating Strategy

The second of the design problems that has to be solved is the one of cold drafts in the house. When the supply fan is activated, very cold air may be introduced into the house thus causing discomfort to the occupants. Therefore, the supply air must be heated.

The first thing to determine is the amount of heat required to adequately heat the incoming cold air. If we choose a design temperature difference of 37°C and a flow rate of 68L/s then:

$$\begin{aligned} Q &= 1.09 \text{ cfm } T/580 \\ &= 1.09 \times 37 \times 68/580 \\ &= 4.79 \text{ kW} \end{aligned}$$

For these conditions, a 5 kW heater should be adequate.

The second issue is the method of controlling the heater. Three control strategies have been devised. These strategies are:

1. Use a proportional controller set to the house temperature. When the outdoor temperature is higher, the heater will operate at lower power. The incoming air will always be heated to a constant temperature close to that of the house.

2. Do not use a heater but just have the furnace fan run when the supply fan runs. This will mix the air with return air from the house. This may cause problems with cold drafts but does provide the least expensive solution. Another problem is that by tying the supply fan switch into the furnace fan, there may be a violation of CGA standards and this may void furnace approval.

3. Activate the furnace fan and the heater (not proportionally controlled) when the supply fan runs. A thermostatic controller in the supply air duct turns on the heater at or below 10°C. At 10°C, the heater will

warm the air to say 50°C. In cold conditions, such as -30°C, the heater would warm the air to 10°C. Having a range of incoming air temperature from 10°C to 50°C could be tolerable because the incoming air is mixed with return air from the house. Again, there could be problems caused by interfering with the furnace.

It was concluded that the possible discomfort introduced by Strategy 2 was undesirable, and that the extra cost of Strategy 1 compared to Strategy 3 would be justified by the energy savings and the extra comfort. Therefore, Strategy 1 was adopted.

3.0 THE SYSTEM DESIGN

3.1 Duct Heater Assembly

Figure 1.0 shows a schematic diagram of the duct heater assembly, and Figure 2.0 shows the wiring diagram. Table 1.0 gives a vendor and parts list. Simply, it consists of a proportionally controlled duct heater and an axial flow fan, with a thermistor to sense the temperature of the heated air. Pictures of duct heaters are provided in Figure 3.0.

3.2 Duct Heater

The first step when assembling the duct heater is the mounting of internal components. Self-tapping sheet metal screws are used to mount the high limits, the terminal block, transformer, and ground lug. To mount the control board, #6 x 1" screws are used. The heat sink and triac are mounted to the spacer plate with two #6 x 5/8" screws. The urethane grommet is placed in the 1/2" hole through the back plate and spacer plate. The elements are mounted with self-tapping sheet metal screws onto the spacer plate. The prototype provided has the enclosure fastened to the control box by means of #10 machine screws. However, the drawing has since been changed to allow the use of #8 taptite screws. The adapter plates used are attached to the enclosure by means of self-tapping sheet metal screws. The cover is attached with #8 taptite screws. Another urethane grommet is used for the manual re-set hole.

The duct heater is wired using 14 gauge GTF in all large current carrying wires. (See wiring diagram for terminations.) The 120V supply wires are used to supply the power to the fan. In this way, the power to the fan cannot be cut off without cutting the power to the heater. The transformer used in the prototype is oversized (happened to be available). A 20VA transformer will work without a problem.

The thermistor is mounted in a copper tube. This tube does not need to be copper, a cheaper material can be used. The probe was designed to mount onto the duct by means of a strain relief. The thermistor is soldered to the leads and insulated with heat shrink then inserted into the tube and potted with silicone. The thermistor is left exposed at the end of the probe. The probe is inserted in the duct approximately 12" downstream of the heater.

3.3 Fan

The fan is a Dayton model 4C720 axial flow fan. It runs at 3400 RPM, 115 volts, 29 watts, and blows 110 L/s of air. It is mounted in the duct upstream of the duct heater and runs only at the same time the heater does.

4.0 COSTS

The cost of the apparatus selected in the present project were as follows:

1.	110L/s axial flow fan	$ 90.00
2.	5 kW proportionally controlled heater	300.00
3.	Installation equipment (wires, relays, etc.)	100.00
4.	Installation labour	395.00
	TOTAL	$885.00

It is likely that this is about the same as the cost of similar equipment manufactured in production quantities and distributed across the country. The apparatus will be cheaper to manufacture in large quantities, but distribution costs will balance this saving.

It is probable that fan control Strategy 2 or 3 will prove to be a cheaper option in the long run, since these strategies will greatly reduce the installation costs. The installed cost using one of these strategies will likely be less than $500.

TABLE 1.0

Duct Heater
Vendor And Parts List

DESCRIPTION	VENDOR	PART NO.	QTY USED	UNIT PRICE	TOTAL PRICE
Manual Reset High Limit	Therm-O-Disc	60T14 L160	1	$ 2.50/ea	$ 2.50
Auto Reset High Limit	(Therm-O-Disc) Texas Instruments	Alternate 20601L-113 (L120-4)	1	2.50/ea	2.50
240V-24V Transformer	Frost	FTC4024-3	1	6.00/ea	6.00
2500W-24V Tubefinned Element	Lion Ind.	10068-0101	2	7.00/ea	14.00
Board, THermister, Triac	Lion Ind.	10281 c/w Triac/Thermistor	1 Set	37.00/ea	37.00
Urethane Grommet	Lion Ind.	10091	2	.30/ea	.60
Terminalized Heyco Bushings	Cords Canada	#4471	1	19.28/100	19.28
Terminal block 3 Pole	Westburne Amesco	Buchannan Block #5125	1	2.62/ea	2.62
Ground Lug	Lion Ind.	10092	1	.60/ea	.60
Heat Sink	Zentronics	Wakefield Engineering #1327	1	3.00/ea	3.00
Sheet Metal	Spectrum Mfg.	Submit Drawings	1 Set	25.00/set	25.00
Fastenrs (Assorted)	Anchor construction	Various Product		.75	

REMEDIAL DEVICE 2: A CHIMNEY FAILURE ALARM FOR GAS-FIRED FURNACES

1.0 INTRODUCTION

The object of an alarm system for gas-fired furnaces is to alert occupants of dangerous backdrafting or spillage, when and if such events are occurring.

Installation of an alarm system on an existing furnace could be an appropriate safety measure in a number of circumstances, including:

- Houses where the potential for backdrafting appears to be marginal, because the measured depressurization of the house is close to the safety limit, or because the worst case conditions in the house are unlikely to occur (e.g. 5 fans operating simultaneously). If an alarm sounded, in such a house, the occupants could assess the situation and, depending upon the frequency and severity of the problem, and take appropriate action. An expert diagnosis could be requested, or they might elect to modify the operation of the house to avoid creating a danger situation (for example, by opening a window to supply air to the fireplace, or by cleaning the air intake filter on an air changer to restore ventilation balance in the home).

- Houses that are extremely airtight, both because it is easier to provoke a ventilation imbalance in an airtight house (e.g. by adding a new fan or by blocking a supply inlet), and because the health hazard is greater in an airtight house - since the average air change will be less than a leaky house and pollutant concentrations can rise quickly.

- Houses that have poorly designed ventilation systems, that are prone to spillage or backdrafting, or have a very small safety margin, but defy attempts to improve the chimney performance.

- Houses that might otherwise require costly repairs or changes in lifestyle that are thought to be unacceptable to the householder.

- Houses where a contractor has undertaken extraordinary measures to balance the ventilation systems, but wishes to protect householders from unforeseen problems, and reduce his own liability.

- Houses where extra protection against chimney malfunction is warranted to provide peace-of-mind for the occupants, perhaps due to previous bad experiences.

A project was under taken during the final phase of the Residential Combustion Safety Checklists to develop a suitable alarm system for gas furnaces. A device was designed, built, tested, and, after appropriate improvements, installed and evaluated on several of the failure houses.

2.0 DESIGN FEATURES AND RATIONALE

After a number of prototype designs, a decision was made to produce a device that generated an audible alarm. Initially, an effort was made to develop a system that would shut off the appliance in the event of spillage or backdrafting (as well as alarm the occupants). A combination fail-safe and alarm, however, proved to be more costly and complex than a simple alarm, and increased the potential for installation and operation difficulties.

A fail-safe control also raised questions about certification and manufacturers' warranties - questions which could not be resolved within the time frame of this project. Moreover, an over-ride switch is required for a furnace fail-safe to ensure that the furnace will still keep the house above freezing in the event nobody is home at the time of spillage. Although a simple over-ride switch was developed and tested, the fail-safe approach was rejected in favor of the simplicity of an audible alarm system. An audible alarm is already being used in houses to warn against smoke and fire, and would appear to be an appropriate level of response to backdrafting and spillage hazards.

A decision was made to control the alarm by means of temperature, rather than CO or CO_2, or some combination of these three. CO detectors then available were costly, complex, had a history of unreliability, and, with a threshold detection limit of about 200 ppm, could not protect occupants from poor air quality and chronic health problems. Moreover, the initial research on spillage and backdrafting hazards, conducted as part of the Checklist design phase, indicated that CO is rarely present in significant concentrations during spillage and backdrafting, even when the appliance is operated for extra-ordinarily long periods of time.

A CO_2 sensor would appear to be a much more appropriate device for alarm control than a CO sensor. However, a low-cost, reliable CO2 detector is not currently available in the marketplace (although much research is under way).

A snap thermodisc was selected as a temperature sensor, due to low cost and wide availability. The use of thermistors and solid state circuitry was rejected because of the high initial costs. With increased production they would improve accuracy and reliability, and would allow for greater adjustment of temperature limits.

An automatic re-set thermodisc was selected in preference to a manual re-set. Although a manual re-set has the advantage of alerting the occupants to each and every occurrence, it greatly increases the annoyance factor and could lead to confusion or distress if people failed to understand the re-set procedure or couldn't figure out when and how the spillage might have occurred.

The location of the snap thermodisc was a surprisingly complicated issue. One possibility, proposed by the Canadian Gas Research Institute, was to use two thermodiscs, one in the flue and one inside the overflow vestibule. The thermodisc mounted on the flue connector would be wired in series with a time delay: if the flue didn't warm up within a 10 second period following ignition, a cold backdraft is presumed and the alarm is sounded. The thermodisc mounted in the overflow vestibule would sound the alarm if temperatures were too high, and thus protect against a spillage situation. The problem with this two-thermodisc approach is the relatively high cost of the time delay ($50) and the added complexity.

An alternative approach was chosen. A single thermodisc was located in front of the dilution air inlet, situated in a position that was selected to detect the warmer temperatures resulting from a backdraft event. Because the temperatures resulting from spillage are much higher than backdrafting, this approach also protects against spillage.

This single thermodisc could not be mounted inside the vestibule, because the effect of backdrafting on temperatures in this area was difficult to predict, and in some cases the best location to detect hot gases during backdrafting was inappropriate for detecting spillage. Instead, it was decided to support the thermodisc and alarm in front of, but away from, the furnace inlet, in a location most likely to catch warm gas flow during a backdraft event. The supports would be braced by metal arms extending from the sides of the furnace, or from above. These supporting arms would be designed to swing aside to permit easy servicing of the appliance, but to lock into place at other times to ensure optimum location.

A digital thermometer was used to map the temperatures in front of a furnace during spillage and backdrafting. Figure 4 presents the results of temperatures recorded on a 110,000 BTU/HR Olsen highboy. Spillage was induced by blocking the flue connector. Backdrafting was induced by installing a fan in the chimney top, and adjusting the downflow to approximately 30L/s. Outdoor temperatures were -4°C.

Temperature mapping showed temperatures to be extremely location sensitive, with changes of up to 100°C resulting from a move of 25 mm. Spillage and backdrafting produced very different temperature regimes. The vertical centerline produced the hottest measurements, but temperatures were highest at the upper lip for spillage, and the lower lip for backdrafting. The optimum location appeared to be a central location approximately 50 mm above the lower lip. (See mark on Figure 4.)

A 60°C thermodisc was selected for evaluation. A higher temperature setting might fail to catch backdrafting in colder weather. A lower temperature might be too sensitive to start-up spillage, or radiant heat transfer. The thermodisc automatically re-sets at 120°F.

A single-pole, double-throw thermodisc was selected, to be wired in series with a 24 VAC buzzer and spliced into one of the wires connecting the house thermostat with the gas valve. When the house thermostat calls for heat, current is directed through the thermodisc to the furnace. If temperatures rise above 60°C and the thermodisc snaps, and the current is re-directed to the furnace via the buzzer.

A variety of buzzers were evaluated. The best choice appeared to be a low-cost, metal buzzer (no plastic) with a decibel rating above 85 db. Mounting the buzzer inside a metal electrical box provided protection for wiring and greatly increased the volume of sound.

3.0 ASSEMBLY AND INSTALLATION

The thermodisc and buzzer were mounted in a 100 X 50 X 50 mm electrical box and bolted to an angle iron. The wiring schematic is presented in Figure 5. Table 2 provides details on vendors, part numbers, and costs. Total retail price for a single kit amounted to $22.49. Manufacturers' discounts would certainly reduce the unit price to under $10.

The final product is illustrated in Figure 6. Eight of these "Buzzer Boxes" were fabricated and supplied to the regional field evaluators for use in the application of remedial measures on failure houses. The support brackets consisted of 25 mm angle iron. The iron is easily cut to size on site. Two pieces are mounted onto the furnace sides or plenum walls using #8 x 3/4" sheet metal screws. Insulation space behind the furnace casing prevents these screws from piercing the heat exchanger walls. The buzzer box is pre-mounted on an angle iron which is placed across the two supports and bolted in place using a bolt and wing nut on one side, and a drop-in cotter pin on the other.

4.0 FIELD EVALUATION

Field evaluations were limited to only 3 houses because of difficulties encountered in receiving approval from the Ontario Fuels Safety Branch. The short time period of the project did not allow for certification of the device by the Canadian Gas Association. Certification was not within the mandate of the research project in any case. Unfortunately, the houses designated to receive the alarm in Ontario were serious backdraft failures. Both the householders and the regional field evaluator were disappointed and worried by the Fuels Safety Branch refusal to permit installation without CGA certification.

The field evaluator did not understand the concern over certification, since the device is exclusively a safety measure and is, in fact, separate from the furnace. The householders, one of whom had already suffered from a CO poisoning incident, were informed that the checklist had revealed a potential backdraft hazard, and that the Fuels Safety Branch had assumed all responsibility.

Three B.C. houses were supplied with buzzer boxes. In two of these houses the checklist had indicated spillage and backdraft hazards. The buzzer boxes were installed as an additional safety measure, in conjunction with a number of other remedial measures designed to balance the ventilation systems and improve chimney performance. Field installation required approximately 20 minutes per unit. Additional time was required to test each unit, and to explain the operation to the householders.

The units were tested after installation by temporarily blocking the flue connector and cycling the furnace on and off with the house thermostat. In all cases, the spillage activated the alarm within 45 seconds. The alarm would sound as long as the furnace operated. Unfortunately, the lack of a depressurization fan on-site during the installation, and a three hour travel time to each house, prevented a test of alarm operation under backdraft conditions.

REMEDIAL DEVICE 3: A FAIL-SAFE SPILLAGE SWITCH FOR GAS- FIRED WATER HEATERS

1.0 INTRODUCTION

The objective of the spillage switch, developed for gas-fired water heaters, was to ensure that chimney failure did not result in excessive pollution in indoor air. Gas-fired water heaters were the most common appliance showing signs of regular backdrafting and spillage in the failure houses. Householders wanted the security of a divice that could shut off the water heater, rather than permit heavy spillage combustion gases. Such devices might be appropriate for all gas-filled water heaters, but would be most useful in tighter houses, where the spillage is a greater threat to air quality, and in houses where the vent/pressure test results are close to the MAD limits.

2.0 DESIGN FEATURES AND RATIONALE

The design features, and rationale for the spillage switch, are similar to the chimney failure alarm for furnaces. A thermodisc is mounted in the spillage path, (fixed to the edge of the draft hood), and is used to detect the excess temperature rise associated with either spillage or backdrafting.

Because a gas water heater valve is powered by a thermo-pile, generating only mili-volts, it is not possible to wire an alarm to the appliance. A separate power supply is required to operate an alarm, and the added cost and complexity of providing such power is difficult to justify. A decision was made to reject the alarm approach, in favor of a simple shut-off, in case of failure. Shutting off the hot water heater is less drastic than shutting off the furnace, since hot water is not usually a survival issue.

A single-pole, single-throw thermodisc was wired in series with the thermocouple. The new style of gas valve allows for easy wiring, since terminals to the thermocouple line are exposed on the face of the valve, and all that is required is a stretch of wire to join the valve with the thermodisc. Older style water heaters can be fitted with a thermocouple junction for this purpose. The junction is fitted to the base of the gas valve, after unbolting the thermocouple line. The terminals on the junction can then be wired directly to the thermodisc.

A difficulty with this system, which could not be overcome, was the extermination of the pilot light in the event of failure. When the thermocouple line is broken by a hot thermodisc, the gas is shut off entirely, within several minutes. After a spillage incident, a householder would discover that not only is the house without hot water, but the pilot light needs relighting. For a small percentage of the population, relighting a pilot light could prove to be a difficult task, and expert assistance would be required.

Because pilot lights are sometimes extinguished for other reasons (e.g. a faulty valve or weak thermocouple), a decision was made to use a manual re-set thermodisc. The position of the manual re-set button on the thermodisc, would inform the householder whether a pilot light outage had been caused by hazardous spillage.

Temperature measurements, of spilling and backdrafting water heaters, indicated that temperatures directly adjacent to the draft hood opening were in excess of 100°C. The higher temperatures justified a thermodisc set point higher than furnaces, since this might help to avoid sensitivity to short term spillage, such as often occurs at start-up. Eventually a 82°C thermodisc was selected, because of its wide availability.

A problem with the thermodisc approach is the tendency of some water heaters to backdraft in summertime by short-circuiting through the furnace connector. The hot gases rise as far as the flue junction, and join the cold air flow down the larger flue pipe to the furnace air inlet. In such cases, the hot water heater draft hood may experience no spillage, despite the fact that the chimney is backdrafting. More research is required to evaluate this possibility.

3.0 ASSEMBLY AND INSTALLATION

Part descriptions and costs are listed in Table 3. Total retail cost amounted to $23. With manufacturer's discounts, the cost would be under $10. Figure 6 illustrates the spillage switch, as installed in a failure house.

The thermodisc was pre-wired to the junction to ensure a good connection. If the wires were not carefully soldered, the added resistance would sometimes prevent the gas valve from opening, despite a strong mili-volt output from the thermocouple. A lower resistance thermodisc would improve the applicability of the spillage switch some thermocouples are barely capable of operating the gas valve without the extra wire and switch.

Because the added resistance of the thermodisc might prevent operation of the gas valve on some older water heaters, a procedure was developed to test the thermocouple and valve, prior to installation of the spillage switch. If necessary, the valve or thermocouple could be replaced, concurrent with installation of the switch.

To test the thermocouple output, a junction is fitted into the thermocouple line and the terminals are connected through a mili-volt meter. Output from the thermocouple, with the junction in place, should fall within the range specified by the manufacturer, (e.g. 17 to 35 MV). The pilot flame can then be covered and a mili-volt reading taken at the moment the gas valve shuts off the pilot flame. This drop-out voltage should also lie within manufacturers' specification.